U.S. Department of the Interior
U.S. Geological Survey

Surface-Water-Quality Assessment of the Yakima River Basin, Washington

Overview of Major Findings, 1987–91

Water-Resources Investigations Report 98–4113

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Surface-Water-Quality Assessment of the Yakima River Basin in Washington:

Overview of Major Findings, 1987–91

By JENNIFER L. MORACE, GREGORY J. FUHRER, JOSEPH F. RINELLA, STUART W. MCKENZIE, and OTHERS

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 98–4113

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FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water supply standards; development of remediation plans for a specific contamination problem; operational decisions on industrial, wastewater, or water supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional and national level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 60 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 60 study units and more than two-thirds of the people served by public water supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch

Robert M. Hirsch
Chief Hydrologist

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CONVERSION FACTORS

[SI = International System of units, a modernized metric system of measurement]

Factors for converting SI metric units to inch/pound units

Multiply	By	To obtain
	Length	
micrometer (µm)	0.00003937	inch (in)
millimeter (mm)	.03937	inch
meter (m)	3.281	foot (ft)
kilometer (km)	.6214	mile (mi)
	Area	
square kilometers (km^2)	.386	square miles (mi^2)
	Volume	
milliliter (mL)	.001057	quart (qt)
liter (L)	1.057	quart
liter	.2642	gallon (gal)
	Mass	
nanogram (ηg)	.00000000003527	ounce (oz avoirdupois)
microgram (µg)	.00000003527	ounce
milligram (mg)	.00003527	ounce
gram (g)	.03527	ounce
kilogram (kg)	2.205	pound (lb)
	Temperature	
degrees Celsius (°C)	(1)	degrees Fahrenheit (°F)
	Discharge	
cubic meters per second (m^3/s)	35.31	cubic feet per second (ft^3/s)
	Concentration, In Water	
nanograms per liter (ηg/L)	1	parts per trillion (ppt)
micrograms per liter (µg/L)	1	parts per billion (ppb)
milligrams per liter (mg/L)	1	parts per million (ppm)
	Concentration, In Sediment	
micrograms per gram (µg/g)	1	ppm
micrograms per kilogram (µg/kg)	1	ppt
	Load	
kilograms per day (kg/d)	2.205	pounds per day (lb/d)
kilograms per day	.001102	tons per day (t/d)

[1]Temperature °F = 1.8 (Temperature °C) + 32

SYMBOLS AND ABBREVIATIONS USED IN THIS REPORT

2,4-D	(2,4-dichlorophenoxy) acetic acid
CAFO	confined animal feeding operations
col/100 mL	colonies per 100 milliliters of water
DDD	dichlorodiphenyldichloroethane
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
DID	drainage improvement district
DO	dissolved oxygen
E. coli	*Escherichia coli* bacteria
EPA	U.S. Environmental Protection Agency
EPT	Ephemeroptera, Plecoptera, and Trichoptera
EPTC	*S*-ethyl dipropylthiocarbamate
ft/mi	feet per mile
$\mathbf{K_{oc}}$	sediment-water partition coefficient
lb/day	pounds per day
MCL	maximum contaminant level
mL/g	milliliters per gram
NAS-NAE	National Academy of Sciences National Academy of Engineering
NASQAN	U.S. Geological Survey's National Stream Quality Accounting Network
NAWQA	U.S. Geological Survey's National Water-Quality Assessment Program
NCBP	U.S. Fish and Wildlife Service's National Contaminant Biomonitoring Program
NPAI	nonpesticide agricultural intensity
NSCRF	EPA's National Study of Chemical Residues in Fish
PAHs	polycyclic aromatic hydrocarbons
PCBs	polychlorinated biphenyls
pCi/L	picocuries per liter
QMH	qualitative multihabitat
RM	river mile
SRP	soluble reactive phosphorus
USGS	U.S. Geological Survey
WY	water year
<	less than
>	greater than

ACKNOWLEDGMENTS

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Surface-Water-Quality Assessment of the Yakima River Basin in Washington: Overview of Major Findings, 1987–91

By Jennifer L. Morace, Gregory J. Fuhrer, Joseph F. Rinella, Stuart W. McKenzie, *and* Others

ABSTRACT

Surface-water-quality conditions were assessed in the Yakima River Basin, which drains 6,155 square miles of mostly forested, range, and agricultural land in Washington. The Yakima River Basin is one of the most intensively farmed and irrigated areas in the United States, and is often referred to as the "Nation's Fruitbowl." Natural and anthropogenic sources of contaminants and flow regulation control water-quality conditions throughout the basin. This report summarizes the spatial and temporal distribution, sources, and implications of the dissolved oxygen, water temperature, pH, suspended sediment, nutrient, organic compound (pesticide), trace element, fecal indicator bacteria, radionuclide, and aquatic ecology data collected during the 1987–91 water years.

The Yakima River descends from a water surface altitude of 2,449 feet at the foot of Keechelus Dam to 340 feet at its mouth downstream from Horn Rapids Dam near Richland. The basin can be divided into three distinct river reaches on the basis of its physical characteristics. The upper reach, which drains the Kittitas Valley, has a high gradient, with an average streambed slope of 14 feet per mile (ft/mi) over the 74 miles from the foot of Keechelus Dam (river mile [RM] 214.5) to just upstream from Umtanum. The middle reach, which drains the Mid Valley, extends a distance of 33 miles from Umtanum (RM 140.4) to just upstream from Union Gap and also has a high gradient, with an average streambed slope of 11 ft/mi. The lower reach of the Yakima River drains the Lower Valley and has an average streambed slope of 7 ft/mi over the 107 miles from Union Gap (RM 107.2) to the mouth of the Yakima River.

These reaches exhibited differences in water-quality conditions related to the differences in geologic sources of contaminants and land use. Compared with the rest of the basin, the Kittitas Valley and headwaters of the Naches River Subbasin had relatively low concentrations and loads of suspended sediment, nutrients, organic compounds, and fecal indicator bacteria. There were very few failures to meet the Washington State dissolved oxygen standard or exceedances of the water temperature and pH standards in this reach. In general, these areas are considered to be areas of less-degraded water quality in the basin. The pre-Tertiary metamorphic and intrusive rocks of the Cle Elum and Teanaway River Subbasins, however, were found to be significant geologic sources of antimony, arsenic, chromium, copper, mercury, nickel, selenium, and zinc. As a result, the arsenic, chromium, and nickel concentrations measured in the streambed sediment of the Kittitas Valley were 13 to 74 times higher than those measured in the Lower Valley.

The Mid and Lower Valleys had similar water-quality conditions, governed by the intensive agricultural and irrigation activities, highly erosive landscapes, and flow regulation. Most of the failures to meet the Washington State standards for dissolved oxygen and exceedances of the standards for water temperature and pH occurred in the Mid and Lower Valleys. Agricultural drains in the Mid and Lower Valleys were found to be significant sources of nutrients, suspended sediment, pesticides, and fecal indicator bacteria. Downstream from the irrigation diversions near Union Gap, summertime streamflow in the Yakima River was drastically reduced to only a few hundred cubic feet per second. In the lower Yakima River, agricultural return flow typically accounts for as much as 80 percent of the main stem summertime flow near the downstream terminus of the basin. Therefore, the water-quality characteristics of the lower Yakima River resemble those of the agricultural drains. The highest fecal bacteria concentrations (35,000 colonies of *Escherichia coli* per 100 milliliters of water) were measured in the Granger/Sunnyside area, the location of most of the livestock in the basin. The east side area of the Lower Valley (area east of the Yakima River) was the predominant source area for suspended sediment and pesticides in the basin. This area had the largest acreage of irrigated land and generally received the largest application of pesticides. Owing to the highly erosive soils of the area, the suspended sediment load from the east side in June 1989 (320 kilograms per day) was five or more times larger than from any other area, and the loads of several of the more hydrophobic organic compounds were four or more times larger.

An ecological assessment of the Yakima River Basin ranked physical, chemical, and biological conditions at impaired (degraded) sites against reference sites in an effort to understand how land use changes physical and chemical site characteristics and how biota respond to these changes. For this assessment, the basin was divided into four natural ecological categories: (1) Cascades ecoregion, (2) Eastern Cascades Slopes and Foothills ecoregion, (3) Columbia Basin ecoregion, and (4) large rivers. Each of these categories has a unique combination of climate and landscape features that produces a distinctive terrestrial vegetation assemblage. In the combined Cascades and Eastern Cascades site group, which had the fewest impaired sites, the metals index was the only physical and chemical index that indicated any impairment. The moderate levels of impairment noted in the invertebrate and algal communities were not, however, associated with metals, and may have been related to the effects of logging, although the intensity of logging was not directly quantified in this study. Sites in the Columbia Basin site group were all moderately or severely impaired with the exception of the two reference sites (Umtanum Creek and Satus Creek below Dry Creek), which showed no physical, chemical, or biological impairment. Three sites were heavily affected by agriculture (Granger Drain, Moxee Drain, and Spring Creek) and were listed as severely impaired by most of the physical, chemical, and biological condition indices. Agriculture was the primary cause of the impairment of biological communities in this site group. The primary physical and chemical indicators of agricultural effects were nutrients, pesticides, dissolved solids, and substrate embeddedness, which all tended to increase with agricultural intensity. The biological effects of agriculture were manifested by a decrease in the abundance and number of native species of fish and invertebrates, a shift in algal communities to species indicative of eutrophic conditions, and higher abundances. There was also an increase in the abundance and number of nonnative fish species due to the prevalence of fish that are largely tolerant of nutrient-rich conditions. Main stem (large river) sites downstream from the city of Yakima exhibited severe impairment of fish communities associated with high levels of pesticides in fish tissues and the presence of external anomalies on fish.

SUMMARY OF MAJOR ISSUES AND FINDINGS

POTENTIAL TOXICITY

HUMAN HEALTH

Concentrations of several organic compounds, arsenic, mercury, and *E. coli* bacteria in either fish tissue and (or) water samples collected in the Yakima River Basin, particularly downstream from the city of Yakima, have the potential to cause adverse human health effects.

- Most samples of resident fish collected downstream from the city of Yakima had concentrations of DDT and its degradation products (DDT+DDE+DDD), PCBs, chlordane related compounds, dieldrin, toxaphene, and polycyclic aromatic hydrocarbons higher than concentrations expected to result in an increased lifetime cancer risk of 1:1,000,000, using EPA's risk assessment methodology calculations. The highest increased cancer risk was computed to be 600:1,000,000 and was based on the detection of high PCB concentrations in whole resident fish from the Yakima River at Kiona (river mile [RM] 29.9). [p. 74]
- As a result of the DDT+DDE+DDD concentrations measured during this study, the Washington Department of Health (1993) issued a recommendation to "eat fewer bottom fish," particularly largescale sucker, bridgelip sucker, and mountain whitefish, from the Yakima River Basin, particularly from "the lower Yakima River and agricultural drains, from the city of Yakima to the Columbia River." [p. 75]
- When the city of Yakima's finished drinking water supply was analyzed for 67 pesticides in June 1989, the only compound detected was DDE (0.36 nanograms per liter), a breakdown product of DDT. Assuming that a person ingests 2 liters of this water each day, the increased lifetime cancer risk was relatively small (4:1,000,000,000). [p. 70]
- Concentrations of arsenic exceeded the human health screening values (determined for an increased lifetime cancer risk of 1:100,000) for the consumption of aquatic organisms and water in 43 percent of the filtered surface-water samples collected. The sites with exceedances were located predominantly in the Lower Valley, the reach from Union Gap (RM 107.2) to the mouth of the Yakima River. [p. 87]
- Concentrations of mercury exceeded the human health screening values for the consumption of aquatic organisms and water in 4 percent of the filtered surface-water samples collected. In fish muscle samples, however, concentrations of mercury from four sites in the basin exceeded screening values established for children (consumers of an average of about one 6-ounce filet per month), recreational fishermen (5 filets per month), and subsistence fishermen (25 filets per month) for all species of fish sampled. [p. 87]
- Surface-water samples collected during the irrigation season from 11 drains, ditches, wasteways, and canals, most carrying varying amounts of agricultural return flow, exceeded all 4 of the EPA recommended limits for *E. coli* concentrations, based on the degree of risk exposure to gastrointestinal illness from recreational contact with water. These elevated bacteria concentrations coincided with the distribution of cattle, especially in the Granger/Sunnyside area. Water samples from nine sites, most in the Lower Valley, exceeded 200 colonies of fecal coliform bacteria per 100 milliliters of water, the Washington State standard for Class A streams. [p. 93]

AQUATIC LIFE

Exceedances of ambient water-quality standards and criteria for the protection of aquatic organisms were measured for water temperature, pH, dissolved oxygen, pesticides, and trace elements. Most exceedances were detected in the agriculturally dominated Lower Valley.

- Water-quality conditions, based on the data collected in the Cascades and Eastern Cascades Slopes and Foothills ecoregions, generally met Washington State water-quality standards (class AA—extraordinary and class

A—excellent). There was some trace element enrichment (antimony, arsenic, chromium, copper, mercury, nickel, selenium, and zinc) in sediments derived from geologic sources in the Cle Elum, Upper Naches, Teanaway, and Tieton River Subbasins, however, water-quality standards have not been established for sediments.

- Of all the water temperature and pH determinations made throughout the 1986–91 water years, 12 and 11 percent of these values, respectively, exceeded the Washington State standards. During a summer synoptic sampling designed to target minimum dissolved oxygen values, nearly half of the sites sampled failed to meet the State standard. The majority of these exceedances and failures occurred in the Lower Valley. As a result of respiration activity and photosynthesis, most dissolved oxygen concentrations failing to meet the Washington State standards occurred in the early morning and most pH values exceeding the standards occurred in the afternoon. [p. 23, 27]

- Although nitrogen and phosphorus concentrations in water were not compared to any water-quality criteria or standards, it is important to note that if turbidity were to significantly decrease, increased sunlight penetration in the water column could increase eutrophication in the lower Yakima River and result in increased dissolved oxygen, pH concerns, and aquatic growth. [p. 52]

- Pesticides that most frequently exceeded chronic-toxicity water-quality criteria (EPA) or guidelines for the protection of freshwater aquatic life (National Academy of Sciences and National Academy of Engineering) in June 1989 included DDT+DDE+DDD, dieldrin, diazinon, and parathion. Most exceedances of criteria and guidelines for organic compounds in water, sediment, and aquatic biota occurred in agricultural return flows and in the main stem downstream from the city of Yakima. [p. 76]

- Concentrations of cadmium, chromium, copper, iron, lead, mercury, silver, and zinc in filtered and (or) unfiltered water exceeded screening values (based on EPA's ambient water-quality criteria for the protection of aquatic organisms) at two or more sites in the Yakima River Basin during the 1987–91 water years. [p. 87]

TRACE ELEMENT ENRICHMENT

The spatial and temporal patterns observed in trace element concentrations are determined by geologic enrichment and human activities in the basin.

- Geologic enrichment of antimony, arsenic, chromium, copper, mercury, nickel, selenium, and zinc in the pre-Tertiary metamorphic and intrusive rocks of the Kittitas Valley caused elevated concentrations in bed sediments in a pristine area relative to concentrations observed in the Lower Valley. The chromium concentrations measured in bed sediment samples from the Cle Elum and Teanaway River Subbasins exceeded the 95-percent range for Western United States soils. [p. 78]

- Human activities also increased the concentrations of antimony, cadmium, copper, lead, mercury, selenium, and zinc in bed sediment samples from the Mid and Lower Valleys. For example, elevated lead concentrations were found in the soils of former apple orchards where the pesticide lead arsenate was used historically. [p. 84]

- Seasonal patterns of trace element concentrations depended on their source. Elements associated with mineralogy of native sediment, such as chromium, had elevated concentrations in water during the snowmelt and irrigation seasons, with sharp decreases in the late irrigation season coinciding with the curtailment of reservoir releases. Arsenic concentrations, which were affected by human activities, were diluted in Sulphur Creek Wasteway during the irrigation season and elevated during the nonirrigation season when the wasteway received a larger proportion of ground water. In the main stem of the Yakima River, where streamflows were smaller during the irrigation season, arsenic concentrations resembled those in the agricultural drains, because as much as 80 percent of the flow came from the drains.

During the nonirrigation season, arsenic concentrations were diluted by pristine water from upstream sources. [p. 81, 85]

AGRICULTURAL RUNOFF

PESTICIDES

An estimated 3 million kilograms of active organic ingredients were applied in the Yakima River Basin in 1989. More than 110 organic compounds, including those associated with industrial and urban activities and pesticides (used both presently and historically), were detected in streams throughout the basin during the 1987–91 water years. Increases in specific pesticide use generally coincided with increases in the number of pesticide detections in streams.

- The flushing of compounds from soil-pore water, the eroding of soil-sorbed compounds, and the dissolving of compounds from soil and sediment into surface water are major pathways for pesticides to travel from agricultural fields to streams and aquatic biota. Therefore, following pesticide applications in the spring, pesticide loads were the highest when the soils were eroded and transported to the streams in irrigation return flow and storm runoff. [p. 76, 64]
- The east side (area east of the Yakima River downstream from the city of Yakima) was the predominant source area for suspended sediment and pesticides in the basin during the irrigation season. This area had the largest acreage of irrigated land and generally received the largest application of pesticides. Due to the highly erosive soils and the steeper slopes in the area, the suspended sediment load from the east side in June 1989 was five or more times larger than from any other area, and the loads of several of the more hydrophobic compounds were four or more times larger. [p. 68]
- Concentrations of DDT+DDE+DDD detected in agricultural soil samples were higher than those in suspended sediment and streambed sediment samples, which suggests eroding soils from agricultural land were a major source of DDT+DDE+DDD to the streams. [p. 73]

SUSPENDED SEDIMENT

In the Yakima River, suspended sediment concentrations and turbidity increased in a downstream direction, coinciding with increased runoff from agricultural areas.

- In the Kittitas Valley, the median concentrations of suspended sediment samples collected monthly during the 1987–91 water years in the main stem ranged from 3 mg/L (milligrams per liter) in the Yakima River at Cle Elum (a site unaffected by agricultural areas) to 17 mg/L in the Yakima River at Umtanum (a site affected by erosion from agricultural areas in the Kittitas Valley). [p. 29]
- In the Lower Valley, the median suspended sediment concentrations increased from 20 mg/L in the Yakima River at Union Gap to 28 mg/L in the Yakima River at Grandview and 25 mg/L in the Yakima River at Kiona, near the terminus of the basin. The suspended sediment concentration at Grandview reflects local runoff from several agriculturally affected drains, including Sulphur Creek Wasteway, the basin's largest agricultural drain, in which values ranged from 7 to 909 mg/L. [p. 30]

NUTRIENTS

Nutrient concentrations also increased in a downstream direction, coinciding with increased runoff from agricultural areas.

- The largest main stem concentrations were measured at the Grandview and Kiona sites, where the median concentrations of the monthly values during the 1987–91 water years were 4 to 70 times those measured at Cle Elum. [p. 45]
- In the Kittitas Valley, concentrations of total nitrogen and total phosphorus in Wilson Creek and Cherry Creek, both of which drain agricultural land, were 7 to 25 times larger than those measured at Cle Elum during the July 1988 synoptic sampling. Downstream from the creeks, the abundant streamflow in the upper

reach of the main stem diluted these high nutrient concentrations. [p. 45]

- Sulphur Creek Wasteway and several agricultural drains contributed high nutrient concentrations to the main stem in the reach between Union Gap and Kiona. Median concentrations in Sulphur Creek Wasteway measured during the 1987–91 water years were approximately twice those in the main stem at Grandview and Kiona, with the exception of the ammonia concentration, which was about three times larger. [p. 45]

- Total phosphorus concentrations followed the pattern of elevated concentrations during periods of larger streamflows and sediment transport. Therefore, the highest concentrations of total phosphorus in the main stem occurred during the snowmelt season. Seasonal patterns of nitrogen concentrations, however, were controlled by dilution effects, with lower concentrations during periods of larger streamflows. Nitrogen concentrations were, therefore, highest during periods of low flow—irrigation and post-irrigation seasons in the main stem of the Yakima River and post-irrigation and winter seasons in the agricultural drains. [p. 51, 50]

ECOLOGICAL CONDITIONS

BIOLOGICAL CONDITIONS

Biological conditions ranged from unimpaired to severely impaired within the basin, and the level of impairment varied with the type of community considered (fish, invertebrates, or algae). The source of human-caused impairment was agricultural practices, which affected sites in the Lower Valley (Columbia Basin ecoregion).

- Biological conditions of invertebrate and algal communities declined markedly at even relatively low levels of agricultural intensity. Fish showed a more moderate response, probably as a result of greater mobility. [p. 113]

BIOLOGICAL INDICES

Biological indices were more sensitive indicators of site conditions than physical and chemical measures because the biological indices integrated effects arising from a broad range of factors, both measured and unmeasured. For instance, invertebrate and algal communities at some sites had moderate levels of impairment when physical and chemical condition indices indicated no impairment.

- An index of metals contamination did not relate to biological impairment in the upper part of the basin (Kittitas Valley). Invertebrate and algal community condition indices suggest that conditions at some sites may have declined relative to those at other sites in the Cascades and Eastern Cascades site group. It was beyond the scope of this study to establish the reason for the impairment and the trends in site conditions. [p.110]

BIOLOGICAL COMMUNITIES

Agricultural activities were the primary factors causing the impairment of biological communities in the Lower Valley (Columbia Basin ecoregion). The primary chemical and physical indicators of impairment are nutrients, pesticides, dissolved solids, and substrate embeddedness, which all tend to increase with agricultural intensity.

- Sites in the Lower Valley were all moderately or severely impaired with the exception of the two reference sites (Umtanum Creek at Umtanum and Satus Creek below Dry Creek), which showed no physical, chemical, or biological impairment. Three sites were heavily affected by agricultural practices (Granger Drain at Granger, Moxee Drain near Union Gap, and Spring Creek at Whitstran). Despite similarity in physical and chemical impairment levels, Cherry Creek at Thrall, Satus Creek at gage, and Wide Hollow Creek at Union Gap all had levels of pesticides that were much higher than at Ahtanum Creek at Union Gap, although the levels of agricultural intensity were similar. Therefore, it is probable that community conditions in Ahtanum Creek could rapidly degrade if agricultural intensity or pesticide contamination were to increase even by relatively modest amounts. [p. 110]

- The biological effects of agricultural practices are manifested by a decrease in the number of species (taxa richness) and abundance of fish and invertebrates, a shift in algal communities to species indicative of eutrophic conditions, and higher abundances. [p. 112]

FUTURE CONSIDERATIONS

SUSPENDED SEDIMENT AND NUTRIENTS

Conservation measures that minimize soil erosion will minimize suspended sediment and nutrient concentrations in Yakima River Basin streams.

- The major source of suspended sediment and turbidity in the Yakima River Basin during the irrigation season is agricultural activity. Tillage processes commonly used in the basin leave the land highly susceptible to erosion by irrigation activity. High rates of sediment transport to tributaries were generally associated with the growing of hops. Apple and pear orchards, however, have reduced erosion by using sprinkler irrigation and grassland covers. [p. 40]
- Although conditions favoring eutrophication existed in the lower main stem during 1992, the low measurements of phytoplankton density and biovolume indicate that stream turbidity may have been inhibiting phytoplankton growth. If turbidity were to significantly decrease, increased sunlight penetration in the water column could increase eutrophication in the lower Yakima River and result in unacceptable levels of dissolved oxygen, pH, and aquatic growth. [p. 52]
- Agricultural fertilizers, suspended sediment, beef and dairy practices, and sewage from municipal and septic tank sources are primary sources of nitrogen and phosphorus. [p. 62]
- The large streamflows associated with the snowmelt season were important in the transport of suspended sediment and associated nutrients from the Yakima River Basin to the Columbia River. As a result, streamflow management activities that increase the storage of snowmelt runoff may reduce the flushing or transport of sediment sorbed nutrients out of the upper basin and consequently decrease the supply of nutrients to nuisance aquatic plants in the lower basin. [p. 62]

PESTICIDES

Responsible use of agricultural pesticides which includes considering the physical and chemical properties of the pesticides, methods of irrigation, and environmental setting—will help control the transport and fate of pesticides.

- Pesticides with one or more of the following characteristics will minimize the likelihood of pesticide transport from agricultural fields to streams: (1) half-lives in soils and water of less than 3 weeks, to increase the likelihood of the compounds to degrade in the fields prior to stream transport; (2) water solubilities less than 30 mg/L, to minimize dissolution and flushing of pesticides from soils; and (3) sediment-water partition coefficient (K_{oc}) values larger than 500 milliliters per gram, to increase the likelihood of the pesticide to remain sorbed to agricultural soils. These characteristics, in concert with reductions in overland runoff and erosion, are key factors that could result in reduced pesticide concentrations in streams. [p. 77]
- Of the four types of irrigation methods used in the Yakima River Basin (rill, flood, sprinkler, and drip), drip (above and below land surface) irrigation is the most effective method for reducing erosion and overland runoff because a minimum amount of water is applied to the land surface and subsurface soils. Drip irrigation is not, however, an appropriate irrigation method for all crops. [p. 77]
- Other factors that affect pesticide transport to streams include: timing of irrigation and storm runoff relative to pesticide application and the likelihood for increased overland runoff, location of pesticide application relative to the potential for stream contamination, method of pesticide application (ground vehicle sprays, aerial sprays, and chemigation), and use of

grass cover crops to help hold the soil in place. [p. 77]

- Pesticide and nutrient effects were strongly correlated, and increased concen-trations were associated with degraded biological communities and habitat. These associations are important to consider when devising management strategies for monitoring and improving water quality. For example, nutrient surveys in place of pesticide surveys could be a cost effective means of monitoring agricultural effects on invertebrate and algal communities. [p. 112]

ECOLOGY

Future monitoring and mitigation efforts that focus on relations among water quality, land use, and ecological conditions will help achieve effect restoration.

- Monitoring the status of fish communities in the Yakima River would provide managers with an effective tool for protecting the ecosystem and human health. Even though pesticide concentrations at the agriculturally dominated large-river sites exhibit dilution effects, the fish community condition index and the index of pesticides in fish tissues suggest that pesticides are readily accumulated by fish in these systems and even the low levels of pesticides that are in water and suspended sediment are associated with a substantial impairment of the fish community and cause a risk to humans consuming these fish. [p. 112]

- Cost-effective restoration can only be achieved when it is determined whether the biological community responds to changes in land use and, if it does, the form of that response. Modest mitigation efforts in areas of high agricultural intensity probably will not produce meaningful improvement. In contrast, relatively modest mitigation efforts at sites where the level of agricultural intensity is near the impairment threshold will probably produce large improvements in community conditions at relatively modest costs. [p. 113]

- As part of an integrated monitoring program, continue to determine and evaluate relations between water quality and land use. Additionally, initiate programs that are designed to determine the response of invertebrate and algal communities to changes in land use that include low levels of agricultural intensity. Community responses to changes in land use activity can be very rapid even at relatively low land use intensities. [p. 113]

OTHER CONSIDERATIONS

Results from the fecal bacteria, trace element, and fish tissue sampling efforts could be used to good effect by water managers designing future monitoring programs in the Yakima River Basin.

- Concentrations of fecal bacteria exceeded EPA standards for recreational use throughout the lower basin. For maximum cost effectiveness, future monitoring would best be focused in agricultural return flows downstream from livestock areas where some of the largest concentrations were detected. [p. 93]

- Point and nonpoint sources of trace elements need to be monitored and quantified at the subbasin level most effectively to assess the quality of water and sediment in the basin. [p. 88]

- Ground-water inflow into Sulphur Creek Wasteway during the nonirrigation season may result in large concentrations of arsenic, a carcinogen that is detrimental to human health at low concentrations. Monitoring of shallow domestic wells for arsenic in areas of intense irrigation where lead arsenate was most likely applied to crops would facilitate the evaluation of a possible arsenic hazard in drinking water from wells. [p. 88]

- Elevated concentrations of organic compounds and trace elements in fish tissue samples emphasize the need to analyze fish filet samples in an effort to get a better understanding of the contaminant concentrations that fish consumers are ingesting. [p. 74, 87]

INTRODUCTION

One of the most difficult issues facing water managers today is the need to protect the Nation's water resources while supporting urban, industrial, and agricultural activities. Over the last several decades, concern about the water quality of our Nation's waterways has intensified. Federal, Tribal, State, and local agencies, as well as the public in general, recognize the detrimental effects of point and nonpoint sources of pollution to the aquatic environment. Many local governments are limiting the quantity of chemicals entering waterways from point and nonpoint sources by establishing total maximum daily loads. Setting these limits is difficult and generally requires background chemical measurements. For example, attempts to limit point source discharges of copper to a river may be problematic when background contributions from geologically enriched areas are not defined.

A major national concern is the degradation of water quality caused by agricultural runoff, a nonpoint source. Pesticides and fertilizers often are found in agricultural runoff. Although these chemicals greatly enhance the productivity of farmland, their beneficial uses may be at the expense of the aquatic environment. Pesticides can be sources of organic constituents, such as DDT, and trace elements, such as lead and arsenic. Fertilizers may promote eutrophication in surface water, and pesticides and fertilizers can directly contaminate shallow ground water. When present in excessive concentrations, organic compounds and trace elements may be toxic to aquatic organisms and may alter the structure of aquatic communities. Ultimately, the occurrence of these chemicals in streams can be measured in terms of the effects on aquatic communities and human health.

Background

In 1986, Congress approved funds for the U.S. Geological Survey (USGS) to implement a pilot program to test and refine concepts for a National Water-Quality Assessment (NAWQA) program (Hirsch and others, 1988). The Yakima River Basin was one of four surface-water pilot studies selected to refine NAWQA concepts (McKenzie and Rinella, 1987). The Yakima Study began its planning phase in 1986, initiated a data collection phase from 1987 to 1990, and, in 1991, began the report writing phase. This report summarizes the findings of the study with regard to dissolved oxygen, water temperature, pH, suspended sediment, nutrients, organic compounds, trace elements, fecal indicator bacteria, radionuclides, and aquatic ecology.

The full-scale NAWQA program, which began in 1991, entails the operation of about 60 study units covering about 60 to 70 percent of the Nation's water resources (Leahy and others, 1990). The NAWQA program will provide results that are useful in understanding and managing water resources and will address national water-quality issues. Specifically, the goals of the NAWQA program are to:

1. Provide a nationally consistent description of current water-quality conditions for a large part of the nation's water resources;

2. Define long term trends (or lack of trends) in water quality; and

3. Identify, describe, and explain, as possible, the major factors affecting water-quality conditions and trends.

The program is long term and involves a cyclic pattern of 3 years of high-level sampling followed by a period of low-level sampling. This cyclic pattern of sampling is designed to determine existing as well as long-term trends in water quality. The water-quality issues addressed in the program are broad, including topics such as eutrophication, pesticides, volatile organic compounds, major and trace elements[1], suspended sediment, stream temperature, and aquatic biota.

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[1] Although definitions of the terms "major" and "trace" in reference to element concentrations are not precise, substances typically occurring in concentrations of less than 1,000 parts per million (< 0.1 percent) are considered trace elements (Forstner and Wittmann, 1979, p. 5). Elements typically occurring in concentrations of greater than 1,000 parts per million are considered major elements. In this report major elements are reported in concentration units of percent and trace elements are reported in concentration units of micrograms per gram (µg/g) for streambed sediment samples and micrograms per liter (µg/L) for water samples.

Purpose and Scope

This report is an overview of significant findings of the pilot NAWQA study in the Yakima River Basin, Washington. It is intended to direct the reader to specific subjects of interest in addition to providing a synopsis of water-quality conditions in the Yakima River Basin for the period 1987–91.

The purpose of this surface-water study was to identify and describe:

1. The occurrence and distribution of nutrients, organic compounds, major and trace elements, suspended sediment, fecal indicator bacteria, and aquatic biota (including insects, fish, clams, and vegetation);
2. The temporal variation of water-quality parameters in media that include filtered water[2], unfiltered water[3], suspended sediment, streambed sediment, and aquatic biota;
3. The suitability of surface water for the preservation of aquatic life and protection of human health;
4. The major natural and human-related sources of contaminants in the Yakima River Basin that affect observed water-quality conditions; and
5. The implications of the assessment study with regard to future monitoring activities, assessment studies, and water management.

THE YAKIMA RIVER BASIN

The Yakima River flows 214.5 miles from the outlet of Keechelus Lake in the central Washington Cascades southeasterly to the Columbia River, draining an area of 6,155 square miles (fig. 1; Columbia Basin Inter-Agency Committee, 1964). The Yakima River Basin is one of the most intensively irrigated areas in the United States. The main stem and its largest tributary, the Naches River, are perennial, with peak runoff during peak snowmelt, usually in April and May. The Bureau of Reclamation's Yakima Project has six irrigation divisions and one storage division and provides water to irrigate almost one-half million acres. Its facilities include 6 storage reser-voirs, 416 miles of canals, 1,701 miles of laterals, 30 pumping plants, 145 miles of drains, 2 small hydroelectric plants, and 74 miles of transmission lines (Bonneville Power Administration, 1985). Many of these waterways, most of which are natural streams, convey agricultural runoff and drainage, livestock wastes, and sewage treatment plant effluent to the main stem. Surface-water diversions are equivalent to about 60 percent of the mean annual streamflow from the basin. Return flows downstream from the city of Yakima contribute as much as 80 to 90 percent of the flow in the lower main stem during the irrigation season. A schematic diagram of selected inflows and outflows is shown in figure 2. Many of these inflows carry agricultural return flow.

The Yakima River Basin contains a variety of landforms, including the high peaks and deep valleys of the Cascade Range, broad valleys and basalt ridges of the Columbia Plateau, and lowlands. Altitude in the basin ranges from 340 ft (feet) at the mouth of the Yakima River to 8,184 ft in the headwaters, located in the Cascade Range. Glaciation has carved deep valleys in the high mountains, and streams and small glaciers continue to erode the already steep slopes. Mean annual precipitation in the basin ranges from 140 inches per year in the mountains to less than 10 inches per year in Kennewick, near the mouth of the basin. The central and eastern parts of the basin consist of basalt flows that form a series of east-northeast to east-southeast trending valleys and ridges. The eastern part is more arid than the western part, which is forested and mountainous.

Before 1880, annual anadromous fish runs numbered more than 500,000 adults in the Yakima River Basin (Rinella, McKenzie, and Fuhrer, 1992b). By the 1980s, anadromous fish runs had declined to 4,000 adults per year (Bonneville Power Administration, 1988). The major factors considered to affect fisheries in the basin today are loss of fish habitat, loss of smolts during migration

[2] The term "filtered water" is an operational definition referring to the chemical analysis of that portion of a water suspended sediment sample that passes through a nominal 0.45-µm (micrometer) pore filter.

[3] Conversely, the term "unfiltered water" refers to the chemical analysis of a water sample that has not been filtered or centrifuged, nor in any way altered from the original matrix.

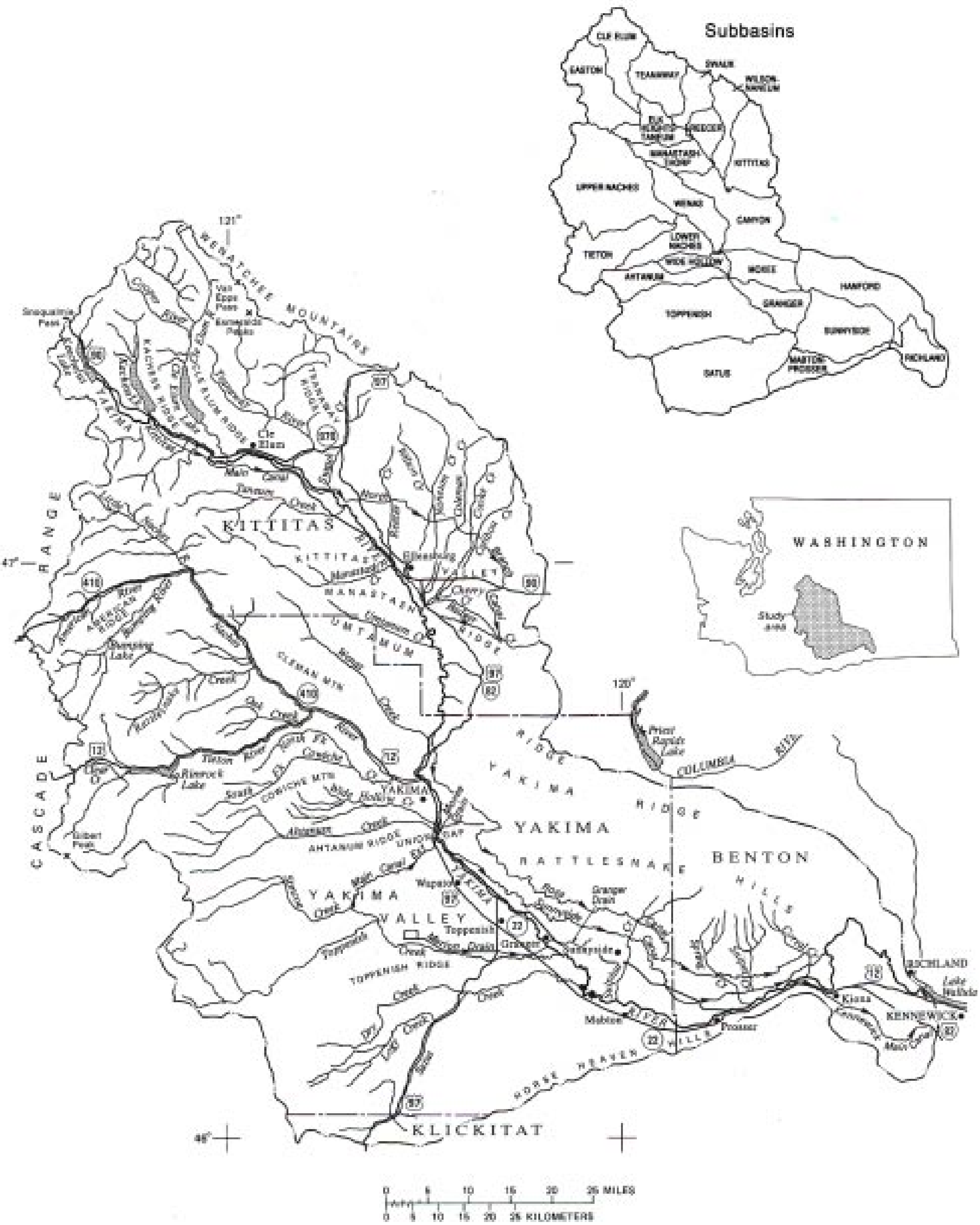


Figure 1. The Yakima River Basin, Washington.

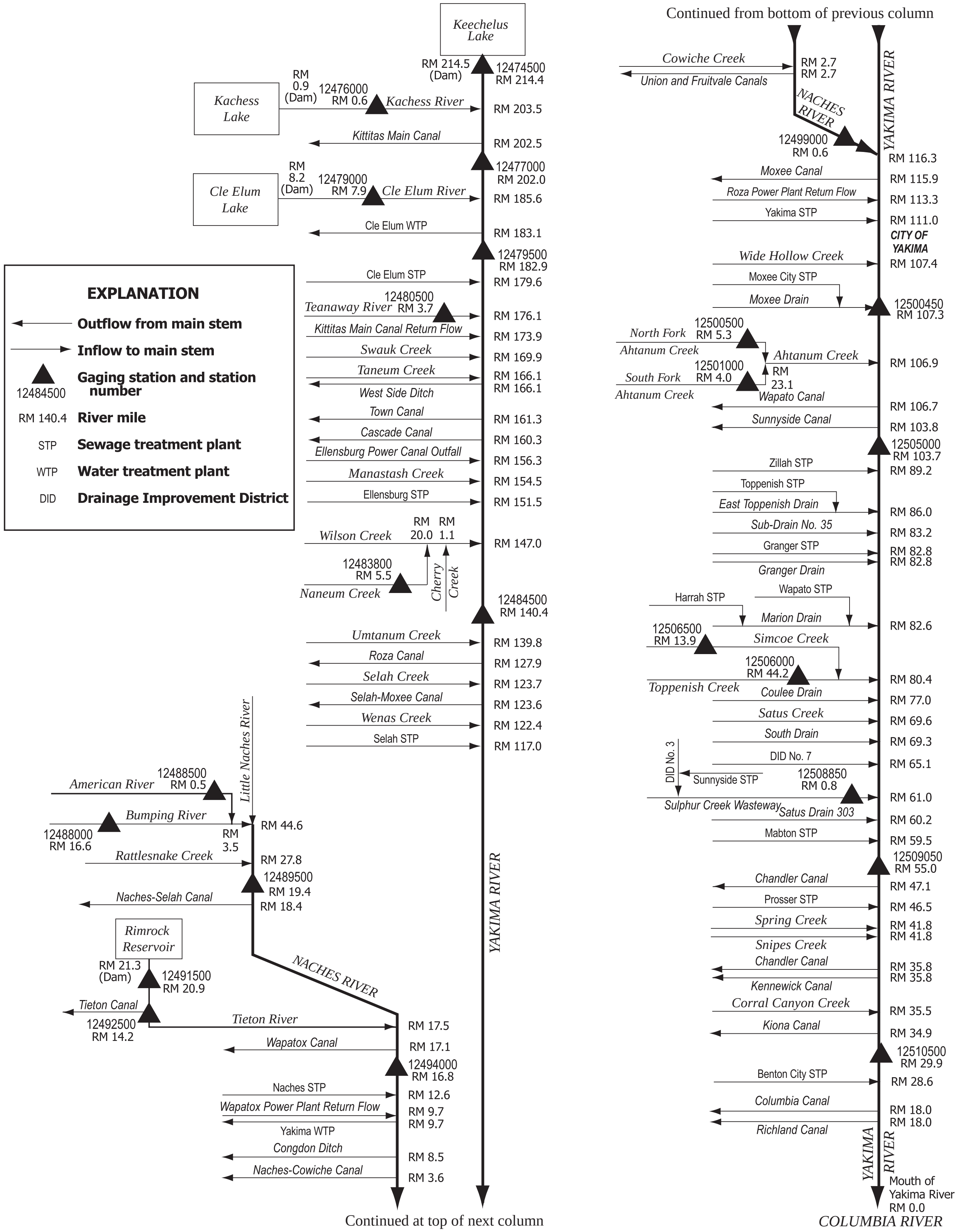


Figure 2. Relative positions of selected tributaries, diversion canals, return flows, and stream-gaging stations in the Yakima River Basin, Washington.

down the Yakima and Columbia Rivers to the ocean, fishing demands on the Columbia River and in the ocean, and poor water-quality conditions.

Stream Reaches

The Yakima River descends from a water surface altitude of 2,449 ft at the foot of Keechelus Dam to 340 ft at its mouth downstream from Horn Rapids Dam near Richland (fig. 3). The headwaters of Keechelus Lake and other tributaries flowing to the lake range in altitude from about 2,500 ft to more than 6,000 ft on the eastern slopes of the Cascade Mountains. The Yakima River Basin can be divided into three distinctive river reaches on the basis of its physical characteristics (fig. 3). The upper reach, which drains the **Kittitas Valley**, is a steep gradient stream with an average streambed slope of 14 ft/mi (feet per mile) over the 74 miles from the foot of Keechelus Dam (river mile [RM] 214.5) to just upstream from Umtanum. In this reach, the river is shallow and the streambed is composed mostly of cobble and large gravel with some boulders, sand, and silt. Rocks are lightly covered with periphyton and are slightly embedded in sediment.

The middle reach, which drains the **Mid Valley** and extends a distance of 33 miles from Umtanum (RM 140.4) to just upstream from Union Gap, is also a steep gradient stream with an average streambed slope of 11 ft/mi (fig. 3). The Roza Dam, located on the Yakima River at RM 127.9, serves to raise the hydraulic head of the river to divert water into an irrigation canal. Several waterways, including Wilson Creek and Moxee Drain, carry sediment-laden irrigation return flow to the middle reach during the irrigation season (approximately March 15 through October 15). Typical suspended sediment concentrations during the irrigation season were about 100 mg/L (milligrams per liter) and 650 mg/L for Wilson Creek and Moxee Drain, respectively. Some of this sediment-laden water is, in turn, diverted into the Roza, Wapato, and Sunnyside irrigation canals. Sediment also is deposited in low velocity backwaters of the middle reach, whereas the fine-fraction sediment is transported farther down the main stem. Similar to the upper reach, the middle reach is shallow, and the streambed is composed mostly of cobble and large gravel with some boulders, sand, and silt. In general, the rocks are slightly embedded and covered lightly to moderately with periphyton, and the streambed is free of rooted aquatic plants. The substrate in the backwater of the Roza Dam, however, is predominantly silt and clay with some organic matter and supports rooted aquatic plants.

The Naches River, a major tributary with 1,106 square miles of drainage area, flows into the Mid Valley at RM 116.3. The Naches River is a steep gradient stream with an average streambed slope of 36 ft/mi. It ranges in altitude from 2,560 ft at the confluence of the Little Naches and Bumping Rivers to 1,070 ft at its mouth. (Headwaters of the Naches River have water surface altitudes as high as 6,000 ft.) The river is shallow and the streambed is composed mostly of cobble and large gravel with some boulders, sand, and silt. Rocks are covered lightly to moderately with periphyton and are slightly embedded in sediment. The vegetative cover and thin soil mantle of the upper Naches Subbasin limit the amount of suspended sediment in the stream. Steep river gradients tend to keep most sediment suspended until the Naches River flows into the middle reach where velocities decrease.

The lower reach of the Yakima River drains the **Lower Valley** and has an average streambed slope of 7 ft/mi over the 107 miles from Union Gap (RM 107.2) to the mouth of the Yakima River (fig. 3). The streambed slope, streamflow, and average water velocity vary throughout this reach. During the irrigation season, streamflow is diverted to the Wapato and Sunnyside canals. As a result, the streamflow in the main stem downstream of these diversions is commonly less than several hundred cubic feet per second. Streamflows remain low until irrigation water returns to the main stem by waterways between Parker (RM 104.6) and Mabton (RM 59.8). During the 1974–81 irrigation seasons, as much as 80 percent of the mean monthly irrigation return at Kiona was from tributaries carrying irrigation return flow between Parker and Kiona (Rinella, McKenzie, and Fuhrer, 1992b). The upstream part of the lower reach of the Yakima River has a steep channel slope (12.8 ft/mi) that decreases midway through the reach (0.9 ft/mi) and

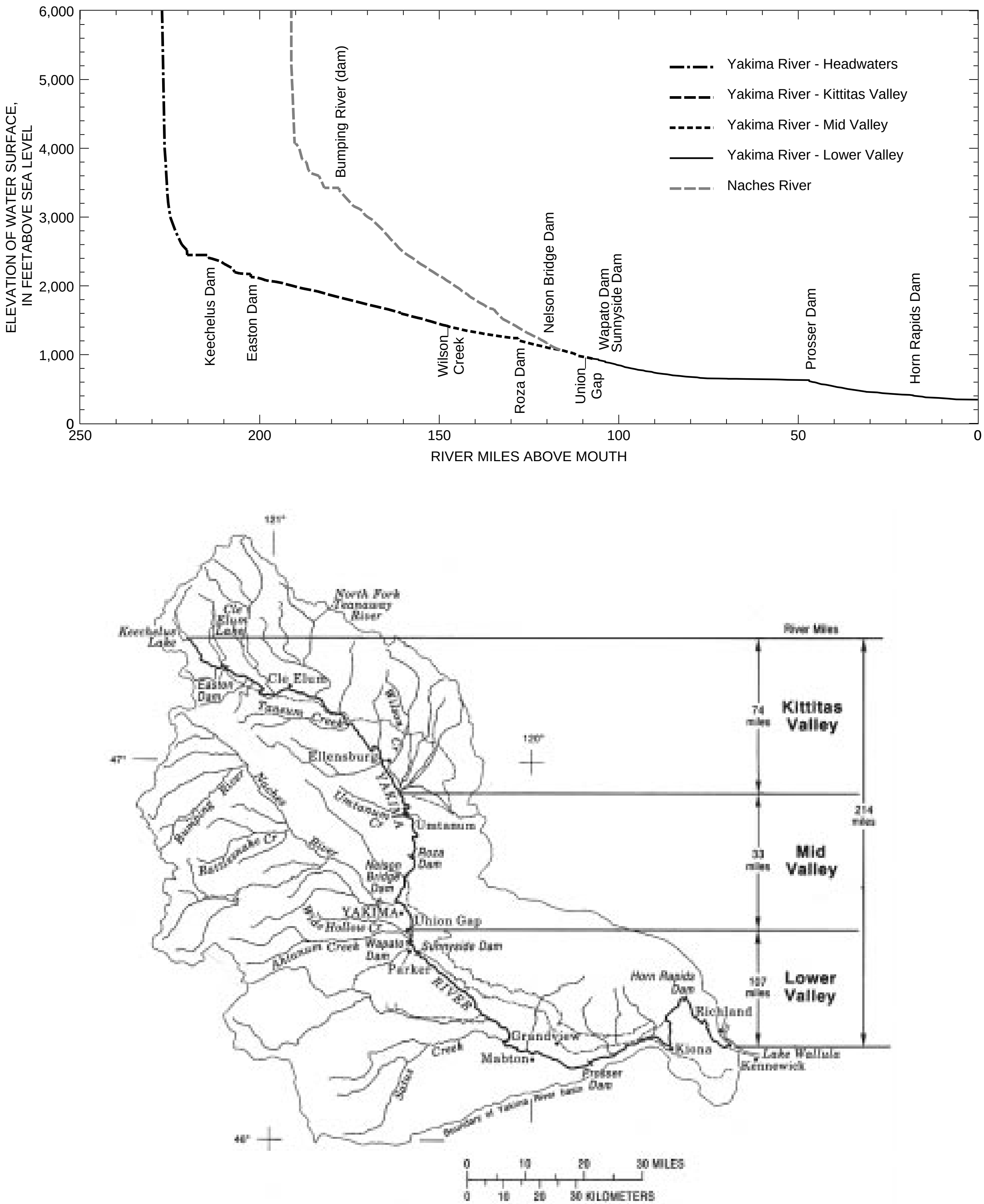


Figure 3. Elevation profile and distinctive hydrologic reaches of the Yakima River, Washington.

evolves into a slow moving, meandering pool. The pool, located upstream from the Euclid Road bridge (RM 55) near Grandview, is hydraulically characterized as a stilling basin behind a bedrock control. The pool is a depositional reach and contains predominantly silt, clay, and some small gravel and organic matter. The substrate in the steeper gradient sections, upstream and downstream from the pool, is similar to that of the upper and middle reaches. Rooted aquatic plants are numerous within the lower reach, especially in the vicinity of Horn Rapids Dam (RM 18.0).

Ecoregions

For the purposes of assessing ecological conditions, an ecoregion approach rather than a stream reach approach was used. The Yakima River Basin is composed of three natural divisions, or ecoregions: Cascades, Eastern Cascades Slopes and Foothills (Eastern Cascades), and Columbia Basin (Omernik, 1987). Each of these ecoregions (shown in fig. 34 on p. 111) represents a unique combination of landscape features that produce a distinctive terrestrial vegetation and climate. Large-river sites in each ecoregion were combined into a separate large-river group because fish, benthic invertebrate, and algal communities of large rivers are known to differ substantially from those of smaller streams (Vannote and others, 1980). This approach provided four natural ecological divisions in which to investigate natural and human effects on water quality and biological communities. Dominant land uses (forestry, agriculture, and urban) were used to depict human-related factors that modify physical, chemical, and biological conditions within these natural divisions.

Geologic Overview

By Marshall W. Gannett

The Yakima River Basin comprises parts of the Columbia Plateau and the Cascade geologic provinces. About two-thirds of the basin, including the entire southern and eastern parts, is in the Columbia Plateau, a province that consists primarily of basalt flows with minor interbedded and overlying sediment. The western and northern margins of the basin are in the Cascade Range (fig. 1). The Cascade Range mountains in the basin consist of a complex assemblage of volcanic, sedimentary, metamorphic, and intrusive rocks.

The Columbia Plateau province is dominated by lavas of the Columbia River Basalt Group, which include the Grande Ronde, Wanapum, and Saddle Mountains Basalts (Walsh and others, 1987). The basalt occurs as multiple flows, each ranging in thickness from 10 to over 100 ft. Compressional forces in the Earth's crust during and after the emplacement of Columbia River Basalt Group lavas have warped and faulted the basalt into a series of east-northeast to east-southeast trending valleys and ridges. The ridges include the Horse Heaven Hills, the Rattlesnake Hills, and Toppenish, Ahtanum, Umtanum, Manastash, Naneum, and Yakima Ridges (fig. 1). Some of the lowlands between these basalt highlands have accumulated significant amounts of sediment. Major sediment accumulations, such as the Ellensburg Formation, are in structural lows of the Kittitas, Selah, Yakima, and Toppenish sedimentary basins according to Smith and others (1989).

Basalt flows of the Columbia River Basalt Group are overlain by, and locally interbedded with, sedimentary deposits. The major sedimentary unit, the Ellensburg Formation, consists chiefly of volcaniclastic material derived from the Cascade Range. Smith and others (1989) report that more than 1,000 ft of coarse-grained volcaniclastic sediment has accumulated over many parts of the Yakima River Basin.

A variety of unconsolidated surficial deposits of Quaternary age is present on the Columbia Plateau in the Yakima River Basin. These deposits include alluvial deposits along rivers and streams, alluvial terrace deposits, loess, and deposits resulting from catastrophic glacial outburst floods that inundated the lower part of the basin during the Pleistocene Epoch (Waitt, 1985). These catastrophic flood deposits are present up to an altitude of about 1,000 ft in parts of the basin.

The remaining one-third of the Yakima River Basin is located in the Cascade Range geologic province and includes parts of the western and northern margins of the basin. The southern part of the Cascade Range in the basin, south of the Naches River, primarily consists of Tertiary volcanic rocks, which include basalt and andesite flows, flow breccias, and related pyroclastic and volcaniclastic rocks (Walsh and others, 1987). Tertiary volcanic units predominate in the middle part of the Tieton drainage, the upper part of the Rattlesnake Creek, most of the American River, Bumping River, and Crow Creek drainages. Older Jurassic to early Cretaceous marine sedimentary rocks are present in the Cascade Range south of the Naches River, particularly in the upper Tieton River drainage. These nonvolcanic rocks consist of sandstone and mudstone with lesser conglomerate (Walsh and others, 1987). North of the Naches River, the Cascade Range province in the Yakima River Basin is dominated by Tertiary nonmarine sedimentary rocks, and pre-Tertiary metamorphic and intrusive rocks with small amounts of Tertiary volcanic rocks.

Major sedimentary units in this area include the Roslyn and Swauk Formations of Eocene age. The Roslyn Formation, which underlies a large part of the Teanaway River drainage, consists primarily of nonmarine sandstone with a smaller amount of conglomerate and thin coal seams (Tabor and others, 1982). The Swauk Formation, which is older than the Roslyn Formation, is located in the upper parts of the Teanaway River, Cle Elum River, and Swauk Creek drainages and consists primarily of nonmarine sandstone and a small amount of siltstone, shale, and conglomerate. The Swauk and Roslyn Formations are separated by the Teanaway Basalt, which consists primarily of basaltic flows, tuff, and breccia.

The upper parts of the south fork of Manastash Creek and the north and south forks of Taneum Creek drain areas underlain by metamorphic rocks of pre-Tertiary age, including gneiss, schist, phyllite and amphibolite. These metamorphic rocks are surrounded and locally overlain by volcanic rocks and nonmarine sedimentary rocks of Tertiary age similar to those of the Swauk and Roslyn Formations. In the far northern part of the Yakima River Basin, the uppermost sections of the Cle Elum River and the north fork of the Teanaway River drain an area underlain by ultramafic rocks adjacent to the Mount Stuart batholith. These ultramafic rocks include serpentinite, serpentinized peridotite, metaserpentinite, metaperidotite, diabase, and gabbro (Tabor and others, 1982). Unconsolidated surficial deposits in the Cascade Province in the Yakima River Basin include alluvium along rivers and streams, alluvial fans, landslides, and glacial drift and outwash.

Land Use

Major land use activities in the Yakima River Basin include growing and harvesting timber, grazing on nonirrigated land, intensively irrigated agriculture, and urbanization (fig. 4). Intense water use for agriculture and cities makes these land use categories of primary importance to water-quality issues. Population in the Yakima River Basin was about 238,000 in 1990 (Yakima Valley Conference of Governments, 1995).

The forested northern and western areas in the Yakima River Basin lie in the Wenatchee and Snoqualmie National Forests, on the eastern slope of the Cascade Range. These forestlands are used for recreation, wildlife habitat, grazing, and timber harvesting. About one-fourth of this area is wilderness land, which has been designated for nonmotorized recreation. Rangelands are used for cattle grazing, wildlife habitat, and military training (at the Yakima Firing Center, northeast of the city of Yakima).

Streamflow Conditions

Winter rain storms and low elevation snowmelt on the east side of the Cascade Range of mountains produces seasonal runoff during January and February. Later in the year, the melting of higher elevation snowpacks produces peak flows in April and May. During the data collection period for the Yakima NAWQA study (1987–91), total precipitation ranged from 80 to 95 percent of normal. As expected, these lower precipitation quantities resulted in lower annual streamflows. The annual mean streamflows for the 1987–89 water years were below normal, and for the 1990–91 water years were near normal. On the basis of historical records from the Yakima River at Kiona

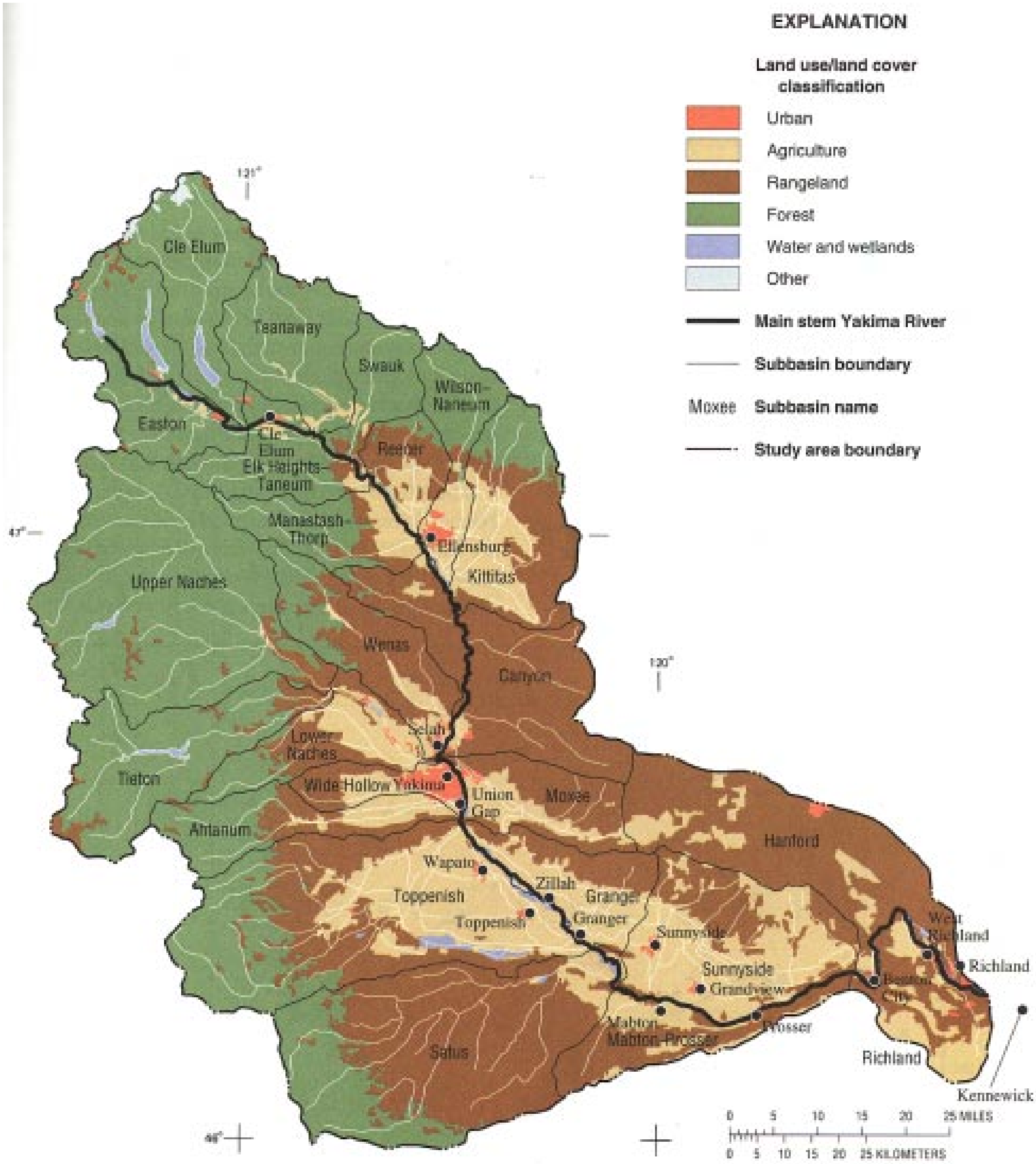


Figure 4. Land use and land cover by subbasin in the Yakima River Basin, Washington, 1981 (U.S. Geological Survey, 1986).

(RM 29.9)—near the terminus of the basin—the mean streamflow for the 1987–91 water years was more similar to the typical median streamflow year than the low streamflow year (fig. 5). The notable difference between the median streamflow year and the data collection period is the lack of the large peak during the snowmelt season of the data collection period. This snowmelt peak in streamflow has implications for the transport of sediment and contaminants.

Seasonal streamflow patterns at seven fixed sites (see p. 20 for identification of the fixed sites) were evident during the 1988–89 water years (table 1). These patterns changed in each of the stream reaches primarily due to the presence or absence of control dams and irrigation diversions. In the Kittitas Valley, the dominant season for high streamflows was the irrigation season because of the large quantity of water released from irrigation reservoirs for subsequent diversion to irrigation canals. For example, the irrigation season streamflows at the Yakima River at Cle Elum represented about two-thirds of the annual streamflow at the site. In a year with significant precipitation during the winter months, the streamflows in the winter and snowmelt periods may be elevated in the Kittitas Valley if the reservoirs reach their storage capacity, necessitating the early release of some of the water. In the Mid Valley, the percentage of annual streamflow accounted for during the irrigation season was lower because part of the flow was diverted from the main stem into the irrigation canals. The snowmelt season streamflows became more significant because of the additional drainage area that lacks reservoirs to store snowmelt. The Naches River, the basin’s largest tributary, transported about one-third of its streamflow during snowmelt and another one-third during the irrigation season. This larger part of streamflow during snowmelt was also due to inputs from the American River, a tributary of the Naches River which has no control dams to dampen the snowmelt effects. The percentages of streamflow in the Lower Valley were more evenly distributed among all of the seasons due to controls

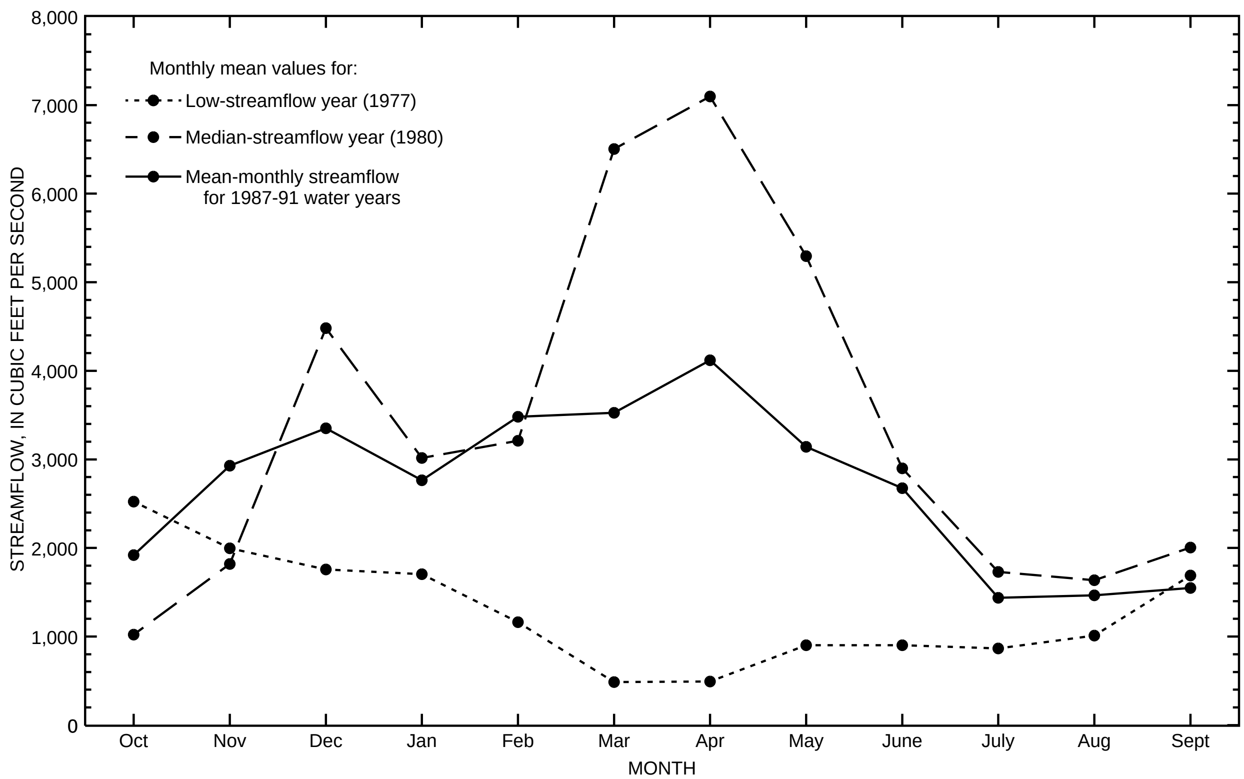


Figure 5. Comparison of monthly streamflows in the Yakima River at Kiona for the 1987–91 water years to a low-streamflow year (1977) and to a median-streamflow year (1980), Yakima River Basin, Washington. (Classification of the low-streamflow and median-streamflow years is based on data from the 1933–90 water years.)

Table 1. Summary statistics for seasonal variations in streamflow at selected sites, Yakima River Basin, Washington, 1988–89 water years

Site name	Yakima River mile	Percent of annual streamflow				Daily mean streamflow (cubic feet per second)			
		Post-irrigation (Oct-Dec)	Winter (Jan-Mar)	Snowmelt (Apr-May)	Irrigation (Jun-Sep)	Post-irrigation (Oct-Dec)	Winter (Jan-Mar)	Snowmelt (Apr-May)	Irrigation (Jun-Sep)
1988 Water Year									
Yakima River at Cle Elum	183.1	6.3	9.9	11.5	72.3	271	428	740	2,330
Yakima River at Umtanum	140.4	7.8	13.3	19.8	59.1	498	862	1,910	2,850
Naches River near North Yakima	116.3	12.0	13.9	36.0	38.1	475	555	2,140	1,130
Yakima River above Ahtanum Creek at Union Gap	107.2	12.1	15.3	26.2	46.4	1,070	1,360	3,480	3,080
Sulphur Creek Wasteway near Sunnyside	61	12.4	16.6	24.3	46.7	86.7	116	255	245
Yakima River near Grandview	55	22.7	28.2	22.8	26.3	1,690	2,130	2,560	1,480
Yakima River at Kiona	29.9	22.8	28.4	23.4	25.3	1,730	2,180	2,680	1,450
1989 Water Year									
Yakima River at Cle Elum	183.1	9.1	9.1	19.6	62.2	523	532	1,690	2,680
Yakima River at Umtanum	140.4	11.2	13.7	25.6	49.5	929	1,160	3,200	3,100
Naches River near North Yakima	116.3	15.3	13.1	37.4	34.2	696	609	2,560	1,170
Yakima River above Ahtanum Creek at Union Gap	107.2	14.8	16.7	30.8	37.8	1,680	1,940	5,290	3,250
Sulphur Creek Wasteway near Sunnyside	61	12.4	10.6	31.1	46.0	103	90.0	390	288
Yakima River near Grandview	55	22.0	25.3	30.4	22.3	2,200	2,580	4,590	1,680
Yakima River at Kiona	29.9	22.1	26.2	31.0	20.7	2,150	2,600	4,560	1,520
1988–89 Water Years									
Yakima River at Cle Elum	183.1	7.9	9.5	16.1	66.5	397	480	1,220	2,510
Yakima River at Umtanum	140.4	9.7	13.5	23.1	53.7	712	1,010	2,560	2,970
Naches River near North Yakima	116.3	13.8	13.5	36.7	36.0	585	582	2,350	1,150
Yakima River above Ahtanum Creek at Union Gap	107.2	13.6	16.0	28.8	41.6	1,380	1,650	4,390	3,170
Sulphur Creek Wasteway near Sunnyside	61	12.4	13.3	28.0	46.3	94.8	103	322	267
Yakima River near Grandview	55	22.3	26.5	27.2	24.0	1,940	2,360	3,580	1,580
Yakima River at Kiona	29.9	22.4	27.2	27.7	22.7	1,940	2,390	3,620	1,480

throughout the entire basin, ground-water seepage, the expanded drainage area, and the diversions of irrigation water.

STUDY DESCRIPTION

The data collection period for the Yakima NAWQA study was from August 1986 through November 1991 and included several different constituents (physical parameters of pH, dissolved oxygen, water temperature, and specific conductance, nutrients, organic compounds, major and trace elements, fecal indicator bacteria, and radionuclides) and media (streambed sediment, suspended sediment, filtered and unfiltered water, and aquatic biota). Detailed descriptions of the field and ana-lytical methods and interpretations of the results are contained in several USGS reports (table 2). These data were obtained during synoptic surveys and scheduled fixed site samplings. Most of the data were collected during **synoptic surveys**. These synoptic surveys were made over a short period (1 to 2 weeks) and provided a broad spatial coverage for the occurrence and distribution of concentrations. To the extent possible, synoptic data were collected during periods of relatively steady streamflows.

Seven sites were established as **fixed sites** (table 3) and were sampled monthly (March 1987–March 1990) and during hydrologic events, such as snowmelt and winter rainstorms (the abbreviated site names given in table 3 will be used throughout the remainder of this report). Five of the seven fixed sites were on the main stem of the Yakima River, one site was located at the mouth of the Naches River—a major tributary, and the other site was located at the mouth of Sulphur Creek Wasteway—a major drain carrying irrigation return flow and urban runoff. These sites were sampled in a systematic downstream order to approximate the movement of surface water passing through the Yakima River Basin. The monthly and event sampling frequency generally provided the temporal coverage necessary to describe seasonal variations.

To characterize temporal variations for constituent concentrations and loads, the data were categorized according to season. The seasons defined for use in this report are **snowmelt**, **irrigation**, **post-irrigation**, and **winter**. The irrigation season (approximately March 15 to October 15) and snowmelt season, however, are not mutually exclusive. Snowmelt generally is a major contributor to streamflow during April and May; consequently, the snowmelt part of the irrigation season is considered separately. As a result, the snowmelt season is defined as April and May, the irrigation season as June through September, the nonirrigation season as October through December, and the winter season as January through March.

Monthly and annual mean daily loads were calculated using a regression model that assumes a linear relationship between the natural logarithm of concentration (log C) and the natural logarithm of streamflow (log Q). The model was created using the ESTIMATOR program, version 94.06 (Cohn, Caulder, and others, 1992). The ESTIMATOR program regresses log C against log Q and the sine and cosine of time (in decimal years, adjusted by 2π, for a yearly cycle) and generates equations for calculating monthly and annual mean daily load estimates. Monthly mean daily loads are the mean of the individual daily mean loads for each month and annual mean daily loads are the mean of the individual daily mean loads for each year.

The ESTIMATOR program uses a minimum variance unbiased estimator (Cohn and others, 1989), which reduces the bias introduced when transforming load estimates from a log-regression equation (log space) back into arithmetic units (real space). The program also incorporates an adjusted maximum likelihood estimator (Cohn, Gilroy, and Baier, 1992) to deal with censored data values, values that are below a specific “detection limit.” The ESTIMATOR program is ideal for use in hydrologic studies, because water-quality data generally show a log C-log Q relationship and commonly contain censored data. The ESTIMATOR program is widely used in the USGS, including about 50 current NAWQA studies. It is also used by the Maryland Department of the Environment on its Chesapeake Bay projects and by the U.S. Army Corps of Engineers.

Table 2. Publications produced by the 1987–91 National Water-Quality Assessment study of the Yakima River Basin, Washington

[Publications are listed in chronological order by their publication date]

U.S. Geological Survey Reports

McKenzie, S.W., and Rinella, J.F., 1987, Surface-water-quality assessment of the Yakima River Basin, Washington—Project description: U.S. Geological Survey Open-File Report 87–238, 35 p.

McKenzie, S.W., and Curtiss, D.A., 1989, Surface-water-quality assessment of the Yakima River Basin, Washington—A pilot study: U.S. Geological Survey Open-File Report 89–60 [pamphlet].

Embrey, S.S., 1992, Surface-water-quality assessment of the Yakima River Basin, Washington—Areal distribution of fecal-indicator bacteria, July 1988: U.S. Geological Survey Open-File Report 91–4073, 34 p.

Rinella, J.F., McKenzie, S.W., Crawford, J.K., Foreman, W.T., Gates, P.M., Fuhrer, G.J., and Janet, M.L., 1992, Surface-water-quality assessment of the Yakima River Basin, Washington—Pesticide and other trace-organic-compound data for water, sediment, soil, and aquatic biota, 1987–91: U.S. Geological Survey Open-File Report 92–644, 154 p.

Rinella, J.F., McKenzie, S.W., and Fuhrer, G.J., 1992a, Executive summary, Surface-water-quality assessment of the Yakima River Basin, Washington—Analysis of available water-quality data through 1985 water year: U.S. Geological Survey Open-File Report 91–454, 15 p.

Rinella, J.F., McKenzie, S.W., and Fuhrer, G.J., 1992b, Surface-water-quality assessment of the Yakima River Basin, Washington—Analysis of available water-quality data through 1985 water year: U.S. Geological Survey Open-File Report 91–453, 244 p.

Ryder, J.L., Sanzolone, R.F., Fuhrer, G.J., and Mosier, E.L., 1992, Surface-water-quality assessment of the Yakima River Basin in Washington—Chemical analyses of major, minor, and trace elements in fine-grained streambed sediment: U.S. Geological Survey Open-File Report 92–520, 60 p.

Rinella, J.F., Hamilton, P.A., and McKenzie, S.W., 1993, Persistence of the DDT pesticide in the Yakima River Basin, Washington—U.S. Geological Circular 1090, 24 p.

Fuhrer, G.J., Fluter, S.L., McKenzie, S.W., Rinella, J. F., Crawford, J. K., Cain, D. J., Hornberger, M.I., Bridges, J.L., and Skach, K.A., 1994, Surface-water-quality assessment of the Yakima River Basin in Washington—Trace element data for water, sediment, and aquatic biota, 1987–91: U.S. Geological Survey Open-File Report 94–308, 223 p.

Fuhrer, G.J., McKenzie, S.W., Rinella, J.F., Sanzolone, R. F., and Skach, K.A., 1994, Surface-water-quality assessment of the Yakima River Basin in Washington—Analysis of major and minor elements in fine-grained streambed sediment, 1987, *with a section on* Geology, by Marshall W. Gannett.: U.S. Geological Survey Open-File Report 93–30, 226 p.

Cuffney, T.F., Meador, M.R., Porter, S.D., and Gurtz, M.E., 1997, Distribution of fish, benthic invertebrate, and algal communities in relation to physical and chemical conditions, Yakima River Basin, Washington, 1990: U.S. Geological Survey Water-Resources Investigations Report 96–4280, 94 p.

Fuhrer, G.J., Cain, D.J., McKenzie, S.W., Rinella, J.F., Crawford, J.K., Skach, K.A., and Hornberger, M.I., 1998, Surface-water-quality assessment of the Yakima River Basin in Washington—Spatial and temporal distribution of trace elements in water, sediment, and aquatic biota, 1987–91: U.S. Geological Survey Water-Supply Paper 2354–A, 190 p. [published previously as U.S. Geological Survey Open-File Report 95–440].

Rinella, J.F., McKenzie, S.W., Crawford, J.K., Foreman, W.T., Fuhrer, G.J., and Morace, J.L., 1999, Surface-water-quality assessment of the Yakima River Basin, Washington—Distribution of pesticides and other organic compounds in water, sediment, and aquatic biota, 1987–91: U.S. Geological Survey Water Supply Paper 2354–B.

Morace, J.L., Fuhrer, G.J., Rinella, J.F., McKenzie, S.W., and others, 1999, Surface-water-quality assessment of the Yakima River Basin, Washington—Overview of major findings: U.S. Geological Survey Water-Resources Investigations Report 98–4113, 119 p.

Table 2. Publications produced by the 1987–91 National Water-Quality Assessment study of the Yakima River Basin, Washington—Continued

Journal Articles

Pankow, J.F., and McKenzie, S.W., 1991, Parameterizing the equilibrium distribution of chemicals between the dissolved, solid particulate matter, and colloidal matter compartments in aqueous systems: Environmental Science & Technology, v. 25, p. 2046–2053.

Foster, G.D., Gates, P.M., Foreman, W.T., McKenzie, S.W., and Rinella, F.A., 1993, Determination of dissolved-phase pesticides in surface water from the Yakima River basin, Washington, using the Goulden large-sample extractor and gas chromatography/mass spectrometry: Environmental Science and Technology, v. 27, p. 1911–1917.

Leland, H.V., 1995, Distribution of phytobenthos in the Yakima River basin, Washington, in relation to geology, land use, and other environmental factors: Canadian Journal of Fisheries and Aquatic Sciences, v. 52, p. 1108–1129.

Carter, J.L., Fend, S.V., and Kennelly, S.S., 1996, The relationships among three habitat scales and stream benthic invertebrate community structure: Freshwater Biology, v. 35, p. 281–299.

Carter, J.L., Fend, S.V., and Kennelly, S.S., 1996, The relationships among three habitat scales and stream benthic invertebrate community structure: Freshwater Biology, v. 35, p. 281–299.

Foreman, W.T., and Gates, P.M., 1997, Matrix-enhanced degradation of *p,p'*-DDT during gas chromatographic analysis—A consideration: Environmental Science and Technology, v. 31, p. 905–910.

Chapter in a book

Fuhrer, G.J., McKenzie, S.W., Rinella, J.F., and Skach, K.A., 1997, Effect of geology and human activities on the distribution of trace elements in water, sediment, and aquatic biota, Yakima River Basin, Washington (1987 to 1991), chap. 14 *in* Laenen, A., and Dunnette, D.A., eds., River Quality—Dynamics and Restoration: New York, Lewis Publishers, p. 187–204.

Pamphlet

Washington Department of Health, 1993, DDT in bottom fish from the Yakima River: Washington Department of Health, Office of Toxic Substances [pamphlet].

Table 3. Fixed sites sampled during the Yakima National Water-Quality Assessment Study, Yakima River Basin, Washington, 1987–91 water years

[RM, river mile; latitude/longitude is reported in degrees (°) minutes (') seconds ("); sites may be referred to by their abbreviated name in this report; the station number can be used for computer retrieval of data from either the U.S. Geological Survey's WATer STOrage and REtrieval system (WATSTORE) or U.S. Environmental Protection Agency's STOrage and RETrieval system (STORET)]

Yakima RM	Site name	Abbreviated site name	Station number	Latitude/longitude
183.1	Yakima River at Cle Elum	Cle Elum	12479500	47°11'35"/120°56'55"
140.4	Yakima River at Umtanum	Umtanum	12484500	46°51'46"/120°28'44"
116.3	Naches River near North Yakima	Naches	12499000	46°34'72"/120°31'10"
107.2	Yakima River above Ahtanum Creek at Union Gap	Union Gap	12500450	46°32'04"/120°27'58"
61	Sulphur Creek Wasteway near Sunnyside	Sulphur Creek	12508850	46°15'03"/120°01'07"
55	Yakima River at Euclid Bridge at RM 55 near Grandview	Grandview	12509050	46°13'01"/119°55'00"
29.9	Yakima River at Kiona	Kiona	12510500	46°15'13"/119°28'37"

WATER-QUALITY CONDITIONS

Dissolved Oxygen, Water Temperature, and pH

By Jennifer L. Morace

Dissolved Oxygen

In order to maintain the health of aquatic communities, the State of Washington classifies streams in part on the basis of required dissolved oxygen (DO) concentrations. Most of the streams in the Yakima River Basin are designated by the Washington Administrative Code (1992) as Class A, in which DO shall exceed 8.0 mg/L. In Class AA streams (headwater streams and the Tieton River), DO shall exceed 9.5 mg/L. Sulphur Creek Wasteway is the only stream in the basin designated as Class B, where the DO shall exceed 6.5 mg/L.

During July 14–19, 1987, a synoptic sampling was performed in which instantaneous DO, water temperature, and barometric pressure were measured before or near sunrise to target minimum DO concentrations (table 4). Of the 39 sites sampled, nearly one-half failed to meet the State standards for DO. Most of these failures were measured in the Lower Valley, where the effects of agricultural return flow, urban runoff, and point source discharges were noticeable. Of particular interest were the failures in the Granger/Sunnyside area, an area largely influenced by the large numbers of confined animal feeding operations (feedlots). The higher bacteria concentrations in feedlot waste result in increased oxygen consumption due to the respiration involved in the breakdown of the organic waste and nitrification of ammonia. This spatial pattern was similar to the pattern noted previously in the Yakima River Basin (Rinella, McKenzie, and Fuhrer, 1992b)—DO concentrations at sites upstream from Granger (RM 82.7) were generally higher than at downstream sites. This, in part, was a function of cooler water temperatures at the upstream sites.

There were also failures to meet the standard in the Kittitas Valley. The lower DO measured in Wilson Creek at Thrall was most likely attributable to farming and livestock influences. Water in thetile drain to Caribou Creek and spring near Caribou Creek was likely affected by subsurface drainage from surrounding agricultural activities. Although these measurements were influenced by ground water, which was expected to have less oxygen than surface water, these sites have some effect on the surface waters.

When comparing the DO data collected during the 1986–91 WY (water years) to the State standards, all of the failures occurred in Class A streams. Only 9 percent of the determinations, but 30 percent of the sites, failed to exceed 8.0 mg/L (table 5). Besides the sites listed in table 4, nine other sites also had failures—five drains, two main stem sites (the Union Gap and Kiona fixed sites), the Naches River fixed site, and Simcoe Creek below Spring Creek. These exceedances occurred during June-October, mostly during the morning.

Water Temperature

The main factors controlling stream temperature are air temperature, solar radiation, humidity, wind velocity, rate of vertical mixing, time of travel, and temperature of inflowing water. Because the upper Yakima River originates from the Cascade Range, the initial stream temperature is cold; however, it warms as it flows to the lower basin. The maximum temperature standards for Class AA and B streams are 16°C (degrees Celsius) and 21°C, respectively (Washington Administrative Code, 1992). The general statewide standard for Class A streams is 18°C, however, the Class A streams in the Yakima River Basin (from the confluence with the Cle Elum River at RM 185.6 to the mouth) have a special standard of 21°C. The Washington Administrative Code states that stream temperatures are not to exceed the maximums due to human activities. When stream temperatures exceed the standards under natural conditions, however, no temperature increase greater than 0.3°C is allowed.

Twelve percent of the 1,152 water temperature measurements from 192 sites during the 1986–91 WY exceeded the State standards (table 5). This percentage is about twice as much as previously published for the Yakima River Basin (Rinella, McKenzie, and Fuhrer, 1992b), although the data set from this study is also much smaller. About 91 percent of the water temperature measurements

Table 4. Dissolved oxygen concentrations and related measures, Yakima River Basin, Washington, July 14–19, 1987

[All sites shown are Class A streams, except Sulphur Creek Wasteway near Sunnyside, which is Class B; DID, Drainage Improvement District; STP, sewage treatment plant; shaded rows indicate those sites which failed to meet the dissolved oxygen standard (Washington Administrative Code, 1992)]

Site name	Station number	Date	Time	Dissolved oxygen (milligrams per liter)	Water temperature (degrees Celsius)	Barometric pressure (millimeters of Hg)
		Kittitas Valley				
Yakima River at Cle Elum	12479500	07–14–87	0645	9.1	13.1	711
Teanaway River below Forks near Cle Elum	12480000	07–14–87	0750	9.2	14.5	705
Naneum Creek near Ellensburg	12483800	07–14–87	0547	9.1	14.6	697
Wilson Creek above Cherry Creek at Thrall	12484100	07–15–87	0630	7.0	14.3	722
Park Creek at Clemens Road at Kittitas	12484225	07–14–87	0625	8.4	15.6	716
Tile Drain to Caribou Creek near Kittitas	12484250	07–14–87	1520	5.4	13.0	708
Spring near Caribou Creek near Kittitas	470218120222900	07–14–87	1440	7.9	13.0	708
Badger Creek at Badger Pocket Road and 4th Parallel Road	12484460	07–14–87	0605	8.5	13.1	717
Cherry Creek at Thrall	12484480	07–15–87	0600	9.9	11.7	722
		Mid Valley				
Yakima River at Umtanum	12484500	07–15–87	0630	9.2	16.1	720
Yakima River above canal diversion at river mile 128 at Roza Dam	12484950	07–15–87	0640	8.0	17.3	726
Naches River at Naches	12494400	07–14–87	0730	9.6	13.3	723
Naches River near North Yakima	12499000	07–15–87	0635	9.2	15.4	729
Moxee Drain at Thorp Road near Union Gap	12500430	07–16–87	0540	8.1	15.3	732
Wide Hollow Creek at mouth at Union Gap	12500445	07–16–87	0740	8.1	12.5	736
		Lower Valley				
Yakima River above Ahtanum Creek at Union Gap	12500450	07–16–87	0630	8.6	15.6	732
Ahtanum Creek at Union Gap	12502500	07–16–87	0655	7.8	14.6	735
Yakima River near Parker	12505000	07–16–87	1000	9.1	15.8	736
Yakima River at river mile 91 at Zillah	12505320	07–17–87	0700	7.6	17.0	735
Granger Drain at mouth at Granger	12505460	07–17–87	0610	8.2	14.3	742
Yakima River at Highway 223 Bridge above Marion Drain	12505465	07–17–87	0630	7.2	16.2	742
Unnamed drain at Branch Road at Yethonat near Wapato	12505475	07–18–87	0616	6.2	15.2	738
Wanity Slough at Meyers Road	12505482	07–18–87	0550	7.0	14.3	735
Marion Drain at Indian Church Road at Granger	12505510	07–18–87	0600	6.4	14.6	735
Toppenish Creek at Indian Church Road near Granger	12507508	07–17–87	0641	6.5	15.3	734
Satus Creek below Dry Creek near Toppenish	12508500	07–17–87	0715	7.8	17.1	730
Satus Creek at gage at Satus	12508620	07–18–87	0620	7.1	14.6	734
Yakima River below Satus Creek at river mile 68 near Satus	12508625	07–17–87	0730	8.0	19.6	738
DID 3 drain below STP at Midvale Road at Sunnyside	12508838	07–17–87	0645	7.5	16.2	736
Sulphur Creek Wasteway near Sunnyside	12508850	07–17–87	0620	8.1	16.6	738
Yakima River at Mabton	12508990	07–17–87	0612	7.6	20.1	738
Yakima River at Euclid Bridge at river mile 55 near Grandview	12509050	07–18–87	0536	7.7	17.9	739
Yakima River at Prosser	12509489	07–18–87	0700	8.1	18.5	739
Yakima River near Bunn Road at Prosser	12509682	07–18–87	0530	8.2	17.3	741
Yakima River near Hosko Road	12509850	07–18–87	0700	9.0	16.7	741
Yakima River above Chandler Pump at river mile 35.9 near Whitstran	12509900	07–18–87	0622	9.0	16.3	741
Yakima River at Kiona	12510500	07–19–87	0650	8.3	18.0	748
Yakima River above Horn Rapids Dam near Richland	12510950	07–19–87	0650	8.3	18.0	748
Yakima River at Van Geisen Bridge near Richland	12511800	07–19–87	0630	7.5	18.7	751

Table 5. Comparison of dissolved oxygen, water temperature, and pH values to Washington State standards, Yakima River Basin, Washington, 1986–91 water years
[mg/L, milligrams per liter; °C, degrees Celsius]

Stream class	Washington State standard[1]	Determinations: Total number of determinations	Determinations: Number not meeting standard	Determinations: Percent not meeting standard	Sites: Total number of sites sampled	Sites: Number not meeting standard	Sites: Percent not meeting standard
Dissolved Oxygen Concentration							
AA	9.5 mg/L	1	0	0	1	0	0
A	8.0 mg/L	317	30	9	82	25	30
B	6.5 mg/L	16	0	0	1	0	0
Water Temperature							
AA	16°C	23	6	26	12	5	42
A	21°C	1,049	134	13	179	67	37
B	21°C	80	4	5	1	1	100
pH							
AA	6.5 – 8.5	16	0	0	7	0	0
A	6.5 – 8.5	769	87	11	135	37	27
B	6.5 – 8.5	71	7	9	1	1	100

[1]Washington Administrative Code, 1992.

were made at Class A streams, 7 percent at Class B streams, and 2 percent at Class AA streams. These measurements were above standards for 26 percent of the measurements at Class AA streams, 13 percent at Class A streams, and 5 percent at Class B streams (table 5). If these exceedances resulted from human activities, then they would be considered violations of the State standards.

All exceedances at the Class AA and B streams occurred during July and August, whereas those at Class A sites occurred during the June-September period. All but four of the Class A exceedances were measured during the 1986 or 1988 WY. This seasonal pattern of exceedances fits with the patterns observed at the fixed sites from 1986–91 WY (fig. 6) and those previously published for the Yakima River Basin (Rinella, McKenzie, and Fuhrer, 1992b). As a note of interest, when the instantaneous water temperature measurements at Sulphur Creek Wasteway were compared to the corresponding daily temperature values (the mean of 24 hourly measurements) recorded by a monitor from April 1987 to April 1990, the measurements were in good agreement.

Eighty percent of the 134 Class A exceedances were in the Lower Valley and included mostly main stem, tributary, canal, and drain sites. The median exceedance temperatures also were higher in the Lower Valley (23.2°C) than in the Kittitas (21.7°C) and Mid (22.0°C) Valleys. This spatial pattern of temperatures increasing downstream was similar to that observed in the main stem from 1986–91 WY (fig. 7) and in data previously published for the main stem Yakima River (Rinella, McKenzie, and Fuhrer, 1992b). Median water temperatures were lowest upstream from Parker (RM 104.6), where the mean base altitude is higher, resulting in cooler air and water temperatures. Much of the summer heating of the river water was associated with (1) low flows downstream from the Wapato (RM 106.7) and Sunnyside (RM 103.8) Canal diversions, (2) slow stream velocities due to a small stream gradient between RM 69.6 and 47.1, and (3) low flows between Prosser Dam (RM 47.1) and Chandler Pumping and Power Plant (RM 35.8).

pH

The pH of a solution is a measure of the hydrogen ion activity and ranges from 0 (very acidic) to 14 (very alkaline), with a pH of 7 indicating a neutral solution. The pH in a stream may change by an influx of either acidic or alkaline wastes and (or) fluctuations in photosynthesis and respiration (due to the uptake and release of carbon dioxide by aquatic plants). Toxicity to freshwater aquatic life can

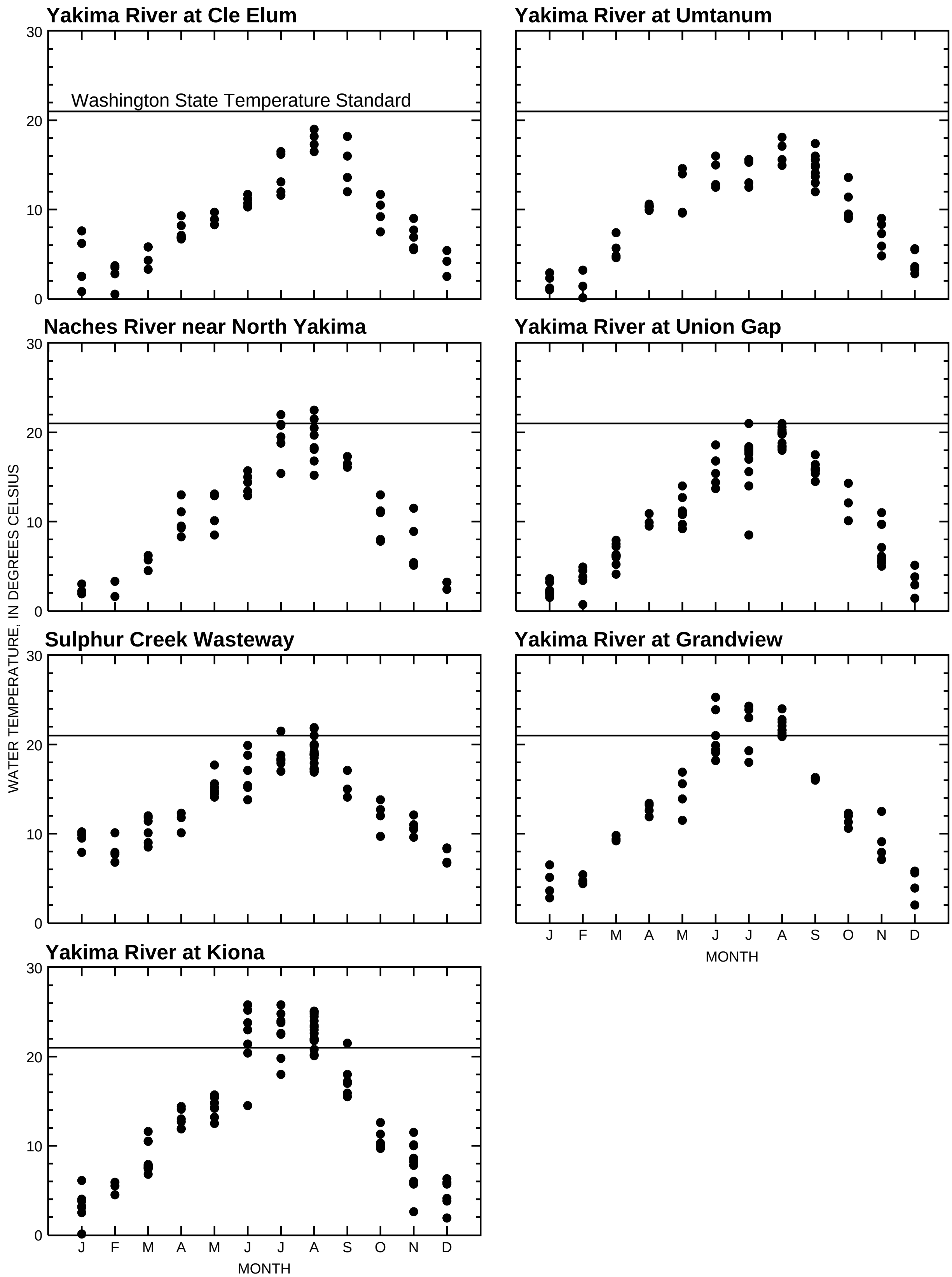


Figure 6. Monthly distribution of instantaneous water temperature at fixed sites, Yakima River Basin, Washington, 1986–91 water years. (Washington State temperature standard is 21 degrees Celsius [Washington Administrative Code, 1992].)

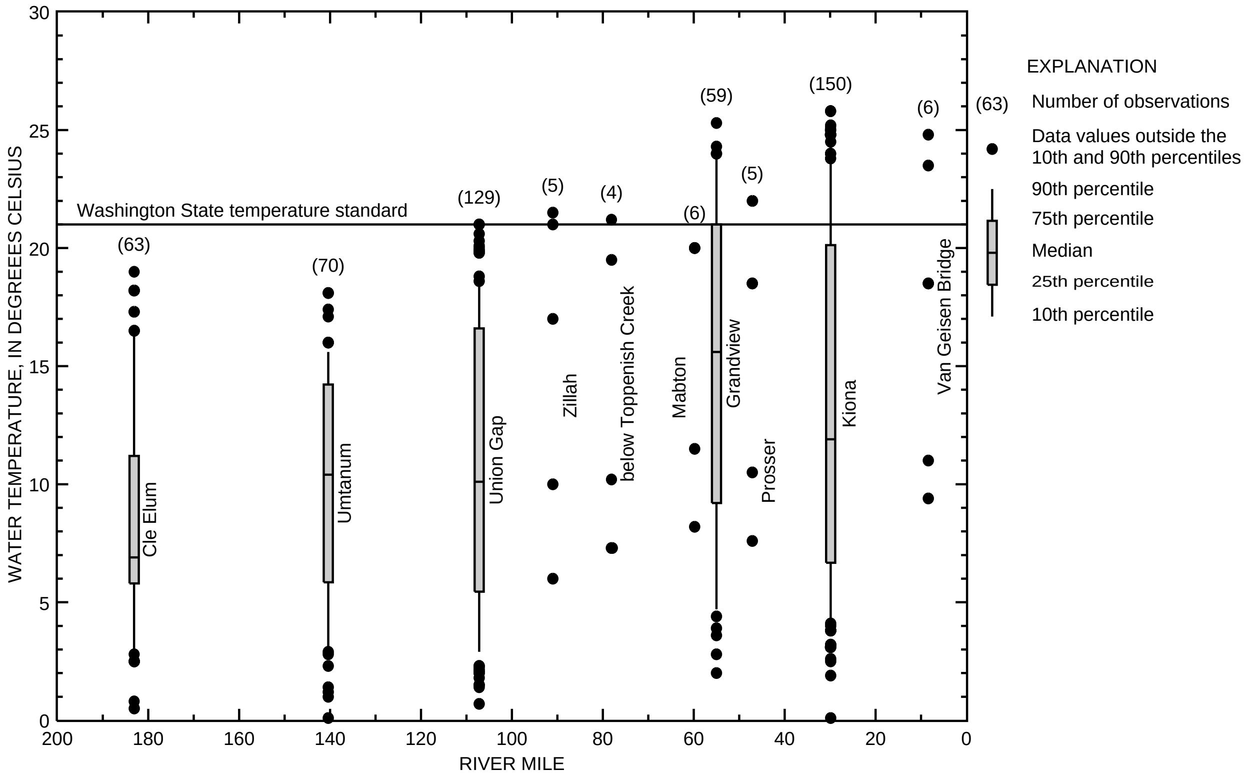


Figure 7. Statistical distribution of water temperature measurements in the Yakima River, Washington, 1986–91 water years. (Washington State temperature standard is 21 degrees Celsius [Washington Administrative Code, 1992].)

occur whenever pH values fall outside the range of 6.5 to 8.5, which corresponds to the water-quality standards set by the Washington Administrative Code (1992) for Class AA, A, and B streams. Aquatic life is indirectly affected by the ability of pH to influence the dissociation of weak acids and bases. As pH increases (more alkaline), for instance, the ammonium ion is dissociated to the toxic unionized ammonia form.

Eleven percent of the 856 pH measurements from 143 sites sampled during the 1986–91 WY did not meet the water-quality standard (table 5). This percentage was higher than data published previously for the Yakima River Basin (3 percent) (Rinella, McKenzie, and Fuhrer, 1992b), although the data set from this study was also only one-tenth the size of the previous data set. Ninety-seven percent of these exceedances had pH values greater than 8.5. Most exceedances were measured during the afternoon and probably were the result of increased photosynthetic activity from aquatic plants. Previously, it had been noted that more of the exceedances occurred in the summer (Rinella, McKenzie, and Fuhrer, 1992b). During the 1986–91 WY, however, this pattern was not as apparent (fig. 8). This may be explained by the uneven monthly distribution of the data.

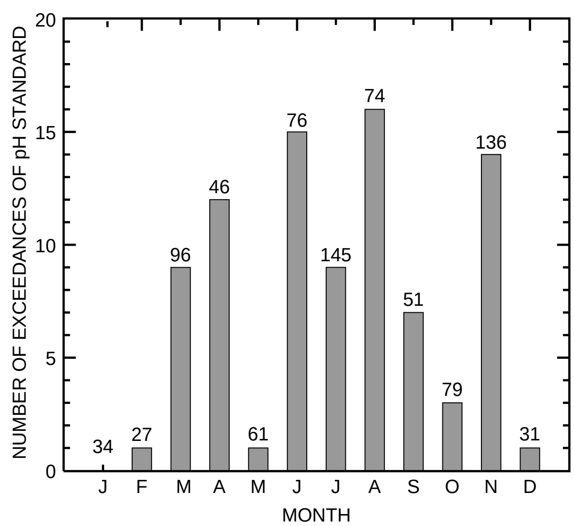


Figure 8.Statistical distribution of pH values not meeting Washington State standards (less than 6.5 or greater than 8.5), Yakima River Basin, Washington, by month, 1986–91 water years. (Reference for State standards is Washington Administrative Code, 1992. Number of measurements is shown above the bar.)

Median pH values down the main stem ranged from 7.7 at Cle Elum to 8.4 at Van Geisen Bridge (fig. 9). The reduced streamflows caused by the Sunnyside and Wapato diversions increased the streambed surface area to water volume ratio, and thus enabled stream productivity due to periphytic growth to increase the daytime stream pH in the reach from Union Gap to Granger. Downstream from Satus (RM 68), all median pH values were greater than 8, probably due to the influence of agricultural inputs, irrigation diversions, and aquatic vegetation in this reach.

The pH values at Kiona ranged from 7.4 to 8.9, thus exceeding the standard at the upper end (fig. 9). At Cle Elum, however, pH values ranged from 6.3 to 8.1 with exceedances on the lower end of the standard range. The value of 6.3 was the only exceedance at Cle Elum, but 4 of the 46 pH determinations were below 7. Three of these four low pH values were measured during the winter of the 1990 WY and also coincided with the latter one-half of winter storms (increases in streamflow). Because the pH of rain water in the Western United States is around 5.5 (Rinella and Miller, 1988) and the headwaters of the basin are relatively pure (pH values less than 7), the flush of these lower pH waters during winter storms would be expected to lower the pH at the Cle Elum site.

Suspended Sediment and Turbidity

By Karen L. Bramblett *and* Gregory J. Fuhrer

An increase in sediment load or concentration may indicate a land use activity that can adversely affect water quality and biological integrity. Large increases in the quantity of sediment delivered to streams as a result of overland runoff and channel erosion can greatly impair or eliminate habitat for aquatic life. Additionally, the transport and fate of

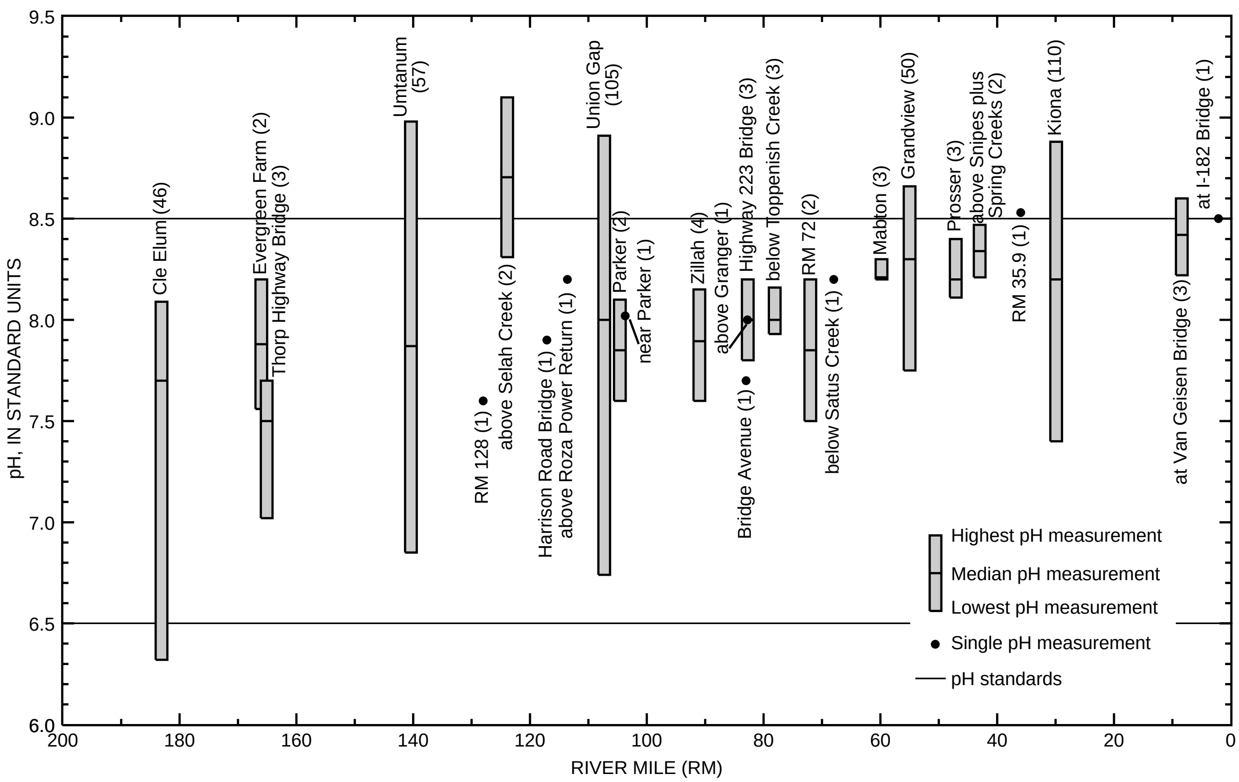


Figure 9. Statistical distribution of pH measurements in the main stem, Yakima River Basin, Washington, 1986–91 water years. (Measurements of pH must be greater than 6.5 and less than 8.5 to meet Washington State pH standards for Class AA, A, or B streams [Washington Administrative Code, 1992]. See table 3 for full fixed site names. Number of measurements is in parentheses after the site name.)

many constituents, including nutrients, organic compounds, trace elements, and fecal indicator bacteria, is associated with suspended sediment. Increases in suspended sediment concentration often cause increases in turbidity, a measurement formulated on the refractory characteristics of suspended material. Even small increases in turbidity can affect the drinking water treatment process by providing areas where microorganisms may not come in contact with chlorine disinfectants. Turbidity also impedes biological primary productivity by reducing light penetration and in turn can adversely affect upper aquatic trophic levels.

Land Use and Land Type Effects

Suspended sediment concentrations and turbidity are affected by land use in the Yakima River Basin. Temporal or seasonal effects also are important for defining land use influences on water quality. For example, spring snowmelt on forest and rangeland, periods of winter storms on land of all uses, and summer irrigation on agricultural land can alter the effect of their associated runoff on water quality. To help understand the relations between land use and water quality, synoptic data were collected during the summer irrigation season (July 26–29, 1988). Rather than make land use assignments on the basis of land use near the sampling site, the predominant sources of water for each site were estimated on the basis of the land and water use of the basin upstream from the sampling location according to the following categories: forest, agriculture, rangeland, and urban.

Although forested and agricultural classifications represented a large percentage of the streamflow, the associated suspended sediment concentrations and turbidity varied greatly among sites (table 6). Tributaries with streamflows predominantly composed of agricultural runoff generally had the highest suspended sediment concentrations, with a median suspended sediment concentration of 27 mg/L, and ranging from 3 mg/L in Ahtanum Creek at Union Gap to 565 mg/L in Moxee Drain at Thorp Road. In contrast, tributaries with streamflow predominantly composed of forested runoff had the lowest concentrations, with a median of 4 mg/L and ranging from <1 mg/L to 10 mg/L.

In the Mid and Lower Valleys, the drainages to the Yakima River can generally be described as low gradient with high organic carbon, silty soils to the west, and high gradient with low organic carbon, sandy soils to the east. The median suspended sediment concentrations during the July 1988 synoptic sampling for the west and east side tributaries were 8 and 138 mg/L, respectively (table 6). Within each of these drainages, however, the specific crops and the methods of tillage and irrigation are important factors controlling suspended sediment concentrations and turbidity levels. For example, a hop field with frequent cultivation and ridge and furrow irrigation would have a much higher rate of erosion than a hop field with underground drip irrigation or an apple orchard with grass undercover and sprinkler irrigations (Bob Stevens, Washington State University soil scientist, oral commun., March 3, 1998).

Rangeland was likely an important land use category during periods of rainfall and runoff. During the summer, however, the contribution to streamflow from rangeland was small, and in terms of land use, its effect on water quality was insignificant; the same was true for the urban areas. Main stem sites also were sampled during the July 1988 synoptic sampling and, like the tributaries, had suspended sediment concentrations that increased as the percentage of streamflow attributable to agricultural areas increased (fig. 10). Downstream from Union Gap, the percentage of streamflow from forested areas decreased from more than 80 percent to less than 30 percent. In contrast, the percentage of streamflow from agricultural areas increased from less than 10 percent to more than 70 percent. In the Lower Valley, the single greatest source of suspended sediment during the synoptic period was from agricultural areas.

Spatial Distribution

In the Yakima River, suspended sediment concentrations and turbidity increased in a downstream direction, coinciding with increased runoff from agricultural areas. For the 1987–91 WY, the median concentrations of suspended sediment in the main stem fixed sites ranged from 3 to 28 mg/L (fig. 11). In the Kittitas Valley, the median concentration of suspended sediment at Cle Elum (a fixed site [site B] unaffected by agricultural areas) was 3 mg/L. Cherry Creek (site C), an agriculturally

Table 6. Streamflow, suspended sediment concentration, and turbidity in tributaries having predominantly forested and agricultural sources of water, Yakima River Basin, Washington, July 26–29, 1988

[If more than one sample was collected at a site, the median concentration is shown here; sites in the Mid and Lower Valleys were classified as east or west side tributaries on the basis of which side of the Yakima River the drainage was located; *, not applicable; <, less than; >, greater than; --, not determined]

Yakima River mile	Site name	East or west side tributary	Streamflow (cubic feet per second)	Suspended sediment concentration (milligrams per liter)	Turbidity (nephelometric turbidity units)
	Predominantly Forested Sources				
176.1	Teanaway River below Forks near Cle Elum	*	37	<1	0.4
154.5	South Fork Manastash Creek near Ellensburg	*	15	5	4.2
147.0	Naneum Creek near Ellensburg	*	13	4	3.4
147.0	Wilson Creek above Cherry Creek at Thrall	*	83	10	7.6
116.3	Naches River near North Yakima	West	355	4	2.8
	Predominantly Agricultural Sources				
147.0	Cherry Creek at Thrall	*	127	82	37
107.4	Wide Hollow Creek near mouth at Union Gap	West	26	8	2.7
107.3	Moxee Drain at Thorp Road near Union Gap	East	76	565	150
106.9	Ahtanum Creek at Union Gap	West	7	3	3.0
86.0	E Toppenish Drain at Wilson Road near Toppenish	West	30	20	9.4
83.2	Sub-Drain Number 35 at Parton Road near Granger	West	34	7	8.0
82.8	Granger Drain at mouth near Granger	East	49	428	>100
82.5	Marion Drain at Indian Church Road near Granger	West	39	7	6.2
80.4	Toppenish Creek at Indian Church Road near Granger	West	54	13	>10
69.6	Satus Creek at gage at Satus	West	84	21	14
61.0	Drainage Improvement District (DID) Number 3	East	26	356	>100
61.0	Sulphur Creek Wasteway near Sunnyside	East	159	113	--
41.8	Spring Creek at mouth at Whitstran	East	24	138	33
41.0	Snipes Creek at mouth at Whitstran	East	24	136	>100
33.5	Corral Canyon Creek at mouth near Benton	East	16	27	3.6

affected tributary in the Kittitas Valley near Ellensburg, had suspended sediment concentrations that ranged from 25 to 1,020 mg/L during the 1988–89 WY.

The effect of agricultural lands on suspended sediment and turbidity was most pronounced in the tributaries and main stem of the Mid and Lower Valley. The main stem received runoff from several agriculturally affected tributaries including Wide Hollow Creek and Moxee Drain. When sampled during the 1988–89 WY, Moxee Drain at Thorp Road (site H) had suspended sediment concentrations that ranged from 47 to 613 mg/L, which were among the highest in the basin. In the main stem of the Lower Valley, the median suspended sediment concentrations increased from 20 mg/L at Union Gap to 28 mg/L at Grandview and 25 mg/L at Kiona, near the terminus of the basin (sites I, N, and O, respectively, in fig. 11). The suspended sediment concentration at Grandview reflects local runoff from several agriculturally affected drains, including the basin's largest agricultural drain, Sulphur Creek Wasteway (site M), in which values ranged from 7 to 909 mg/L.

The suspended sediment and turbidity data collected during the 1987–91 WY fixed site sampling period were generally within 20 percent of the historical data reported by Rinella, McKenzie, and Fuhrer (1992b) for the 1974–81 WY. For example, the median suspended sediment concentration measured at Kiona was 26 mg/L historically and 25 mg/L for the NAWQA study. Median suspended sediment concentrations at the Yakima River at Umtanum (site D) and Sulphur Creek Wasteway (17 and 103 mg/L, respectively) were twice those measured historically (8 and

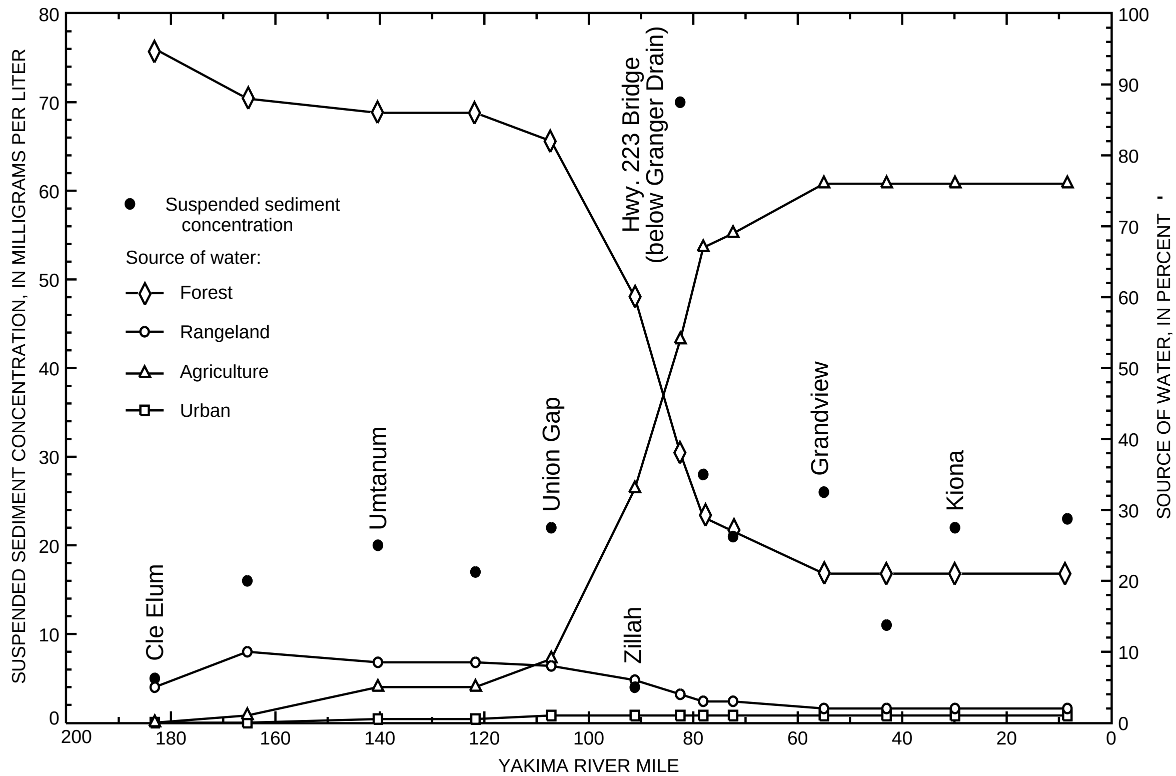


Figure 10.Associations between suspended sediment concentrations and estimated sources of water in the Yakima River, Washington, July 26–29, 1988. (See table 3 for full site names.)

45 mg/L, respectively). These differences cannot be attributed to differences in streamflow among water years—streamflows for the 1987–91 WY were slightly smaller than the median streamflow for the historical period. Differences between historical and 1987–91 WY data may have resulted from increases in erosion in the Kittitas Valley and the Sulphur Creek drainage. Additionally, differences between periods may have resulted from differences in sampling techniques for water samples. Historically, water samples from other agencies were grab samples collected near the water's surface at one point in the stream's cross section. The 1987–91 WY samples, however, were depth and width integrated samples collected at 10 points in the cross section. Grab sampling techniques like those used historically may have been biased by not proportionally integrating larger grain-sized suspended sediment.

During the July 26–29, 1988, synoptic sampling, samples were analyzed for suspended sediment and turbidity at 13 main stem sites and 36 tributary sites. The summer period was selected because it is a time of intense irrigation that may result in the erosional loss of agricultural soils to surface waters. Similar to the fixed site data, the synoptic data showed that the highest suspended sediment concentrations were measured in the agricultural areas of the Mid and Lower Valley, particularly in the tributaries of the Moxee Subbasin and the Roza and Sunnyside Irrigation Districts (fig. 12). The suspended sediment concentration in Moxee Drain at Thorp Road, for example, reached a maximum of 613 mg/L. In contrast, suspended sediment concentrations in the west side tributaries were low. The influence of the east side tributaries on the main stem was the most pronounced just downstream from Granger Drain. The median suspended sediment concentration for the entire main stem was 21 mg/L, however, the concentration at the Highway 223 Bridge near Granger was at a maximum of 70 mg/L. This spike in concentration resulted from the Granger Drain input (421 mg/L) just 0.3 miles upstream from the Highway 223 Bridge site (fig. 12). Farther downstream, much

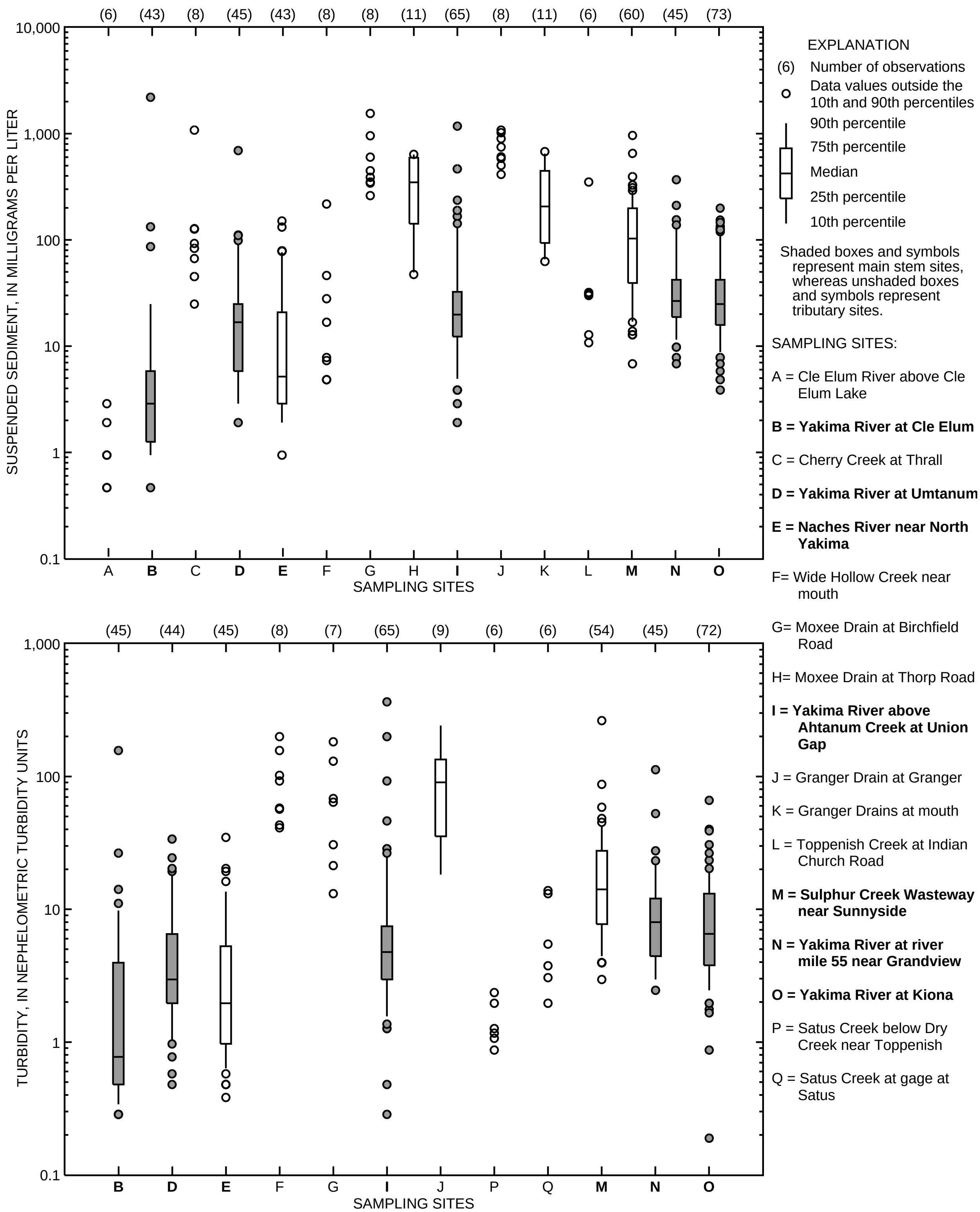
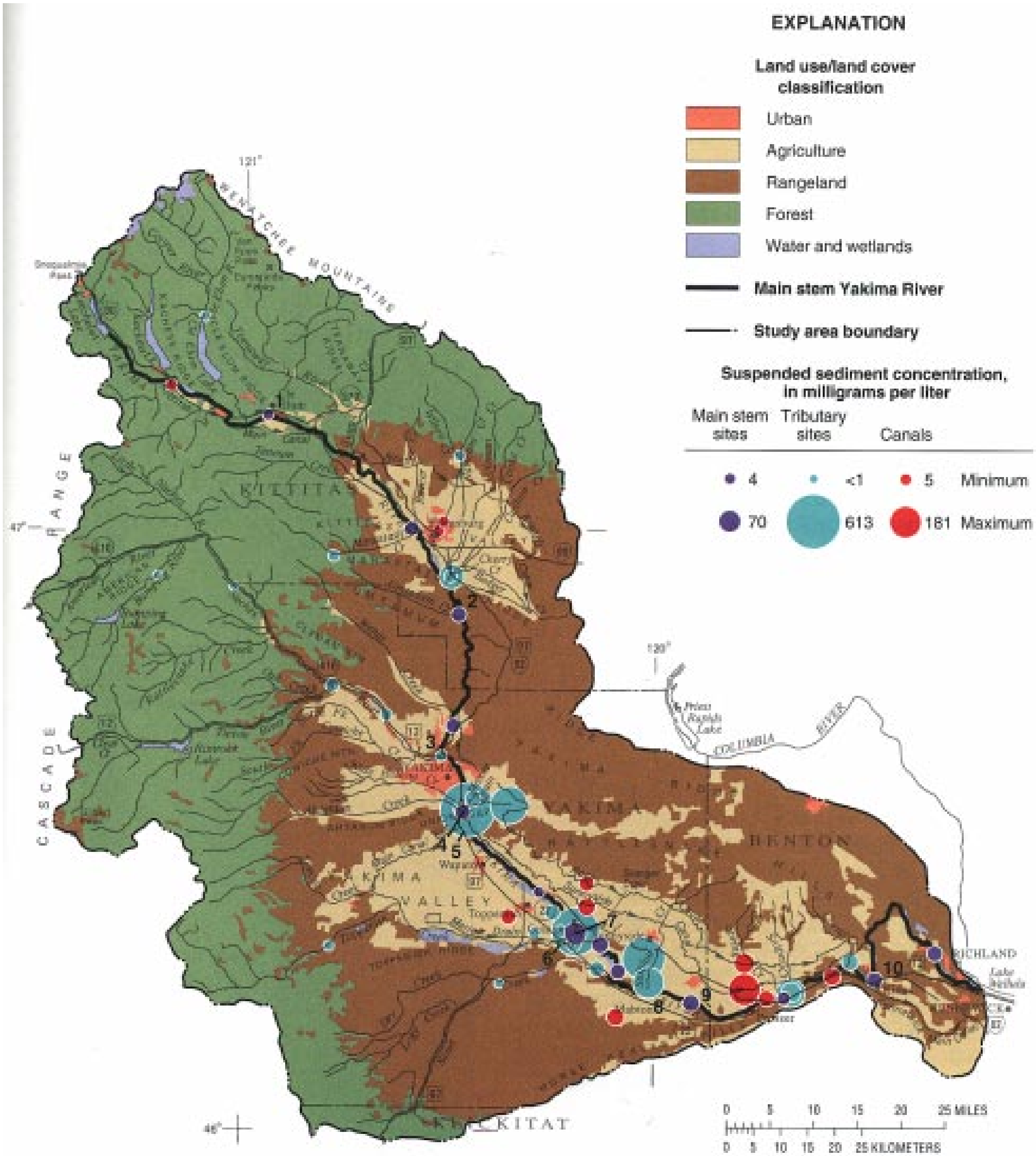


Figure 11. Statistical distribution of suspended sediment concentrations and turbidity measurements, Yakima River Basin, Washington, 1987–91 water years. (Only sites with more than 5 samples are shown. Fixed sites are shown in **bold** print. To avoid statistical bias, only the mean concentration for each day at each site was included. Suspended sediment concentrations lower than the limit of determination [1.0 milligrams per liter] were treated as 0.5 milligrams per liter.)



Map #	Abbreviated site name	mg/L	Map #	Abbreviated site name	mg/L
1	Cle Elum	4	7	Yakima River at Highway 223 Bridge below Granger Drain	70
2	Umtanum	19			
3	Naches	5			
4	Union Gap	20	8	Sulphur Creek	173
5	Moxee Drain at Thorp Road	613	9	Grandview	29
6	Granger Drain at mouth	460	10	Kiona	24

Figure 12. Statistical distribution of suspended sediment concentrations, Yakima River Basin, Washington, July 26–29, 1988. (Symbol sizes are proportional to suspended sediment concentrations; mg/L, milligrams per liter. See table 3 for full

of the suspended sediment had settled out and the main stem concentrations generally ranged from 20 to 30 mg/L.

Temporal Variation

In the Yakima River Basin, suspended sediment concentrations at the fixed sites varied two to three orders of magnitude over the 3 years of sampling (fig. 11). At Union Gap, suspended sediment concentrations ranged from 2 mg/L during the nonirrigation season to 1,110 mg/L during a major spring rain-on-snow event in the Kittitas and Mid Valley, which lasted 2 to 3 days. Seasonal differences in suspended sediment concentrations and turbidity in the main stem were most pronounced when comparing the snowmelt and post-irrigation seasons (fig. 13). An important source of sediment is deposition of agriculturally derived suspended sediment in the main stem during the irrigation season, followed by resuspension during the snowmelt season. In contrast, temporal variations in suspended sediment concentrations at Cle Elum were small and probably reflected the absence of appreciable upstream sources of erodible sediment as well as the settling effect of upstream reservoirs. Peaks in suspended sediment concentration also occurred at the beginning of the irrigation season, when canals and ditches contained sediment from recent mechanical cleaning and wind-blown sources. For example, on March 21, 1989, at Sulphur Creek Wasteway, the suspended sediment concentration was 620 mg/L, exceeding the 90th percentile for the 1987–91 WY sampling period at this site (fig. 11). This elevated concentration was most likely the result of a combination of wind-driven dust and the initial flushing of the canal water from Sunnyside Canal into Sulphur Creek Wasteway.

The sediment deposited in the main stem as a result of the lower streamflows of the irrigation season was not appreciably resuspended and transported until the streamflows increased during the winter and snowmelt seasons. The suspended sediment concentrations at Kiona followed this pattern during the 1988 WY (fig. 14), with the only obvious major changes in concentration having occurred during two winter storms and a snowmelt activity. In contrast, seasonal variations in suspended sediment concentrations in Sulphur

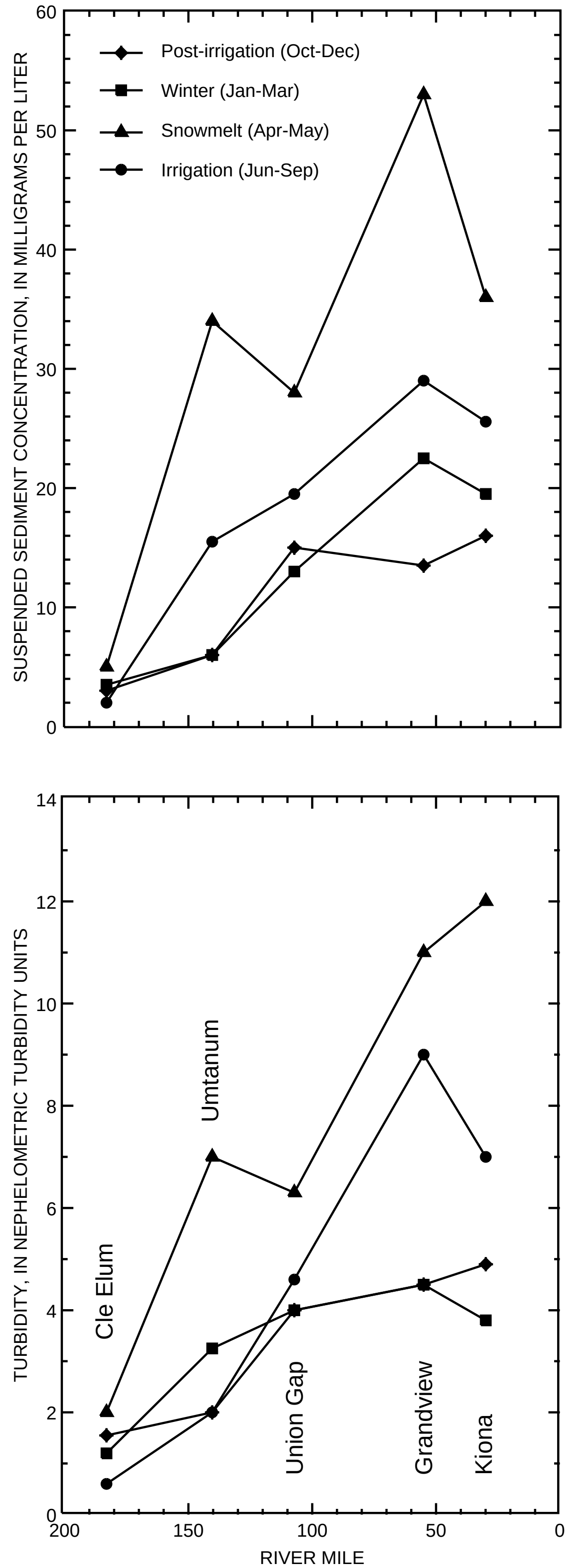


Figure 13. Median suspended sediment concentrations and turbidity measurements in the Yakima River, Washington, 1987–91 water years. (See table 3 for full site names.)

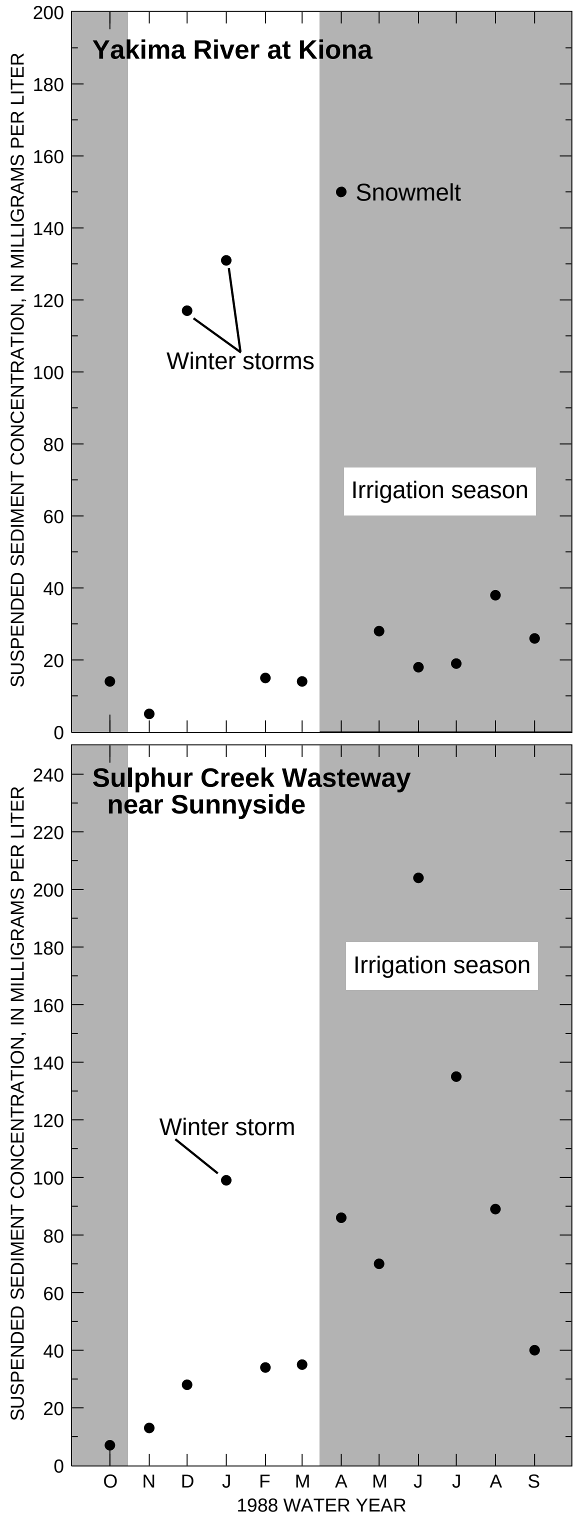


Figure 14. Monthly suspended sediment concentrations in the Yakima River at Kiona and Sulphur Creek Wasteway near Sunnyside, Washington, 1988 water year. (To avoid statistical bias, only the first concentration per month is shown.)

Creek Wasteway were very pronounced during the 1988 WY (fig. 14). During the nonirrigation season, concentrations were less than 50 mg/L (except during a winter storm in January), while during the irrigation season, concentrations were variable and as much as four times larger.

Monthly and Annual Loads

Monthly and annual mean daily suspended sediment loads (table 7) were calculated using ESTIMATOR (see Study Description section for an explanation of the program). Because of the need for daily streamflow measurements and monthly and storm event measurements of suspended sediment, these loads were calculated only at fixed sites. The estimation of monthly and annual loads provided a spatial measure of sediment transport and an understanding of seasonal sediment transport.

During the 1988–89 WY, the suspended sediment loads in the Mid Valley at Umtanum were 3 to 27 times those in the Kittitas Valley at Cle Elum (table 7). The suspended sediment loads at Umtanum were affected by agricultural activities in the Kittitas Valley, whereas the suspended sediment loads at Cle Elum were affected primarily by forested land. Most of the suspended sediment in the Kittitas Valley was transported during the June through August part of the irrigation season. For example, the irrigation season loads at Cle Elum and Umtanum, respectively, accounted for 64 and 66 percent of the total annual loads at these two sites during the 1988–89 WY (table 8). This seasonal pattern resulted from high streamflows typically released from irrigation reservoirs upstream from Cle Elum and the agricultural activities in the vicinity of Ellensburg. In comparison to the suspended sediment load exiting the basin, the total annual load at Umtanum represented 66 percent of the load at Kiona in the 1988 WY.

The suspended sediment loads at Union Gap, affected by Moxee Drain and Wide Hollow Creek in the Mid Valley, were 2 to 15 times the loads at Umtanum, except during the irrigation season when they were generally less than 2 times (table 7). In July and August, irrigation season loads at Umtanum increased with streamflow and slightly exceeded loads at Union Gap. High streamflow,

Table 7. Estimated mean daily suspended sediment loads and annual mean daily streamflow at fixed sites, Yakima River Basin, Washington, 1987–90 water years

[Loads are reported as tons per day; load estimates are based on calibration data collected from March 1987 to March 1990; annual flow represents the annual mean daily streamflow in cubic feet per second; --, no data; Cr, Creek; lightly shaded and darkly shaded cells, respectively, represent the snowmelt portion and the nonsnowmelt portion of the irrigation season; unshaded cells represent the nonirrigation season; see table 3 for full site names]

Site	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual load	Annual flow
1987 Water Year														
Cle Elum	--	--	--	--	--	--	1	10	40	50	50	4	--	--
Umtanum	--	--	--	--	--	--	120	140	270	360	340	43	--	1,744
Naches	--	--	--	--	--	--	200	140	34	10	4	26	--	--
Union Gap	--	--	--	--	--	--	440	1,100	300	260	230	140	--	2,584
Sulphur Cr	--	--	--	--	--	--	180	180	140	120	60	34	--	--
Grandview	--	--	--	--	--	--	330	1,000	110	100	85	80	--	--
Kiona	--	--	--	--	--	--	430	1,400	120	95	70	50	--	2,375
1988 Water Year														
Cle Elum	1	1	2	2	8	7	12	3	12	46	60	13	14	1,075
Umtanum	5	3	10	6	28	38	160	80	150	370	460	140	121	1,608
Naches	14	3	6	4	7	12	140	160	80	14	6	60	43	992
Union Gap	75	37	75	50	100	95	600	360	300	280	310	200	207	2,216
Sulphur Cr	14	5	6	7	10	100	150	160	190	75	65	60	70	175
Grandview	110	75	190	120	210	180	750	330	240	140	140	160	220	1,876
Kiona	75	44	140	65	140	160	700	340	240	85	95	120	184	1,905
1989 Water Year														
Cle Elum	1	5	9	16	10	4	34	48	37	65	50	9	24	1,442
Umtanum	14	28	33	40	33	48	390	320	300	480	400	100	183	2,090
Naches	24	8	8	8	5	14	280	280	160	8	7	60	75	1,144
Union Gap	90	120	120	130	110	180	1,600	1,100	500	320	260	190	389	2,873
Sulphur Cr	22	6	6	6	10	55	280	310	170	120	110	80	98	210
Grandview	200	300	210	200	160	580	3,600	1,600	300	160	140	140	632	2,521
Kiona	100	180	120	110	90	380	2,400	1,200	250	120	120	110	435	2,454
1990 Water Year														
Cle Elum	1	10	14	30	40	16	--	--	--	--	--	--	--	--
Umtanum	32	39	43	65	95	100	--	--	--	--	--	--	--	2,398
Naches	13	6	15	100	22	30	--	--	--	--	--	--	--	--
Union Gap	95	120	150	340	240	270	--	--	--	--	--	--	--	3,302
Sulphur Cr	34	6	6	8	8	95	--	--	--	--	--	--	--	--
Grandview	130	230	220	520	340	310	--	--	--	--	--	--	--	--
Kiona	140	200	210	400	290	340	--	--	--	--	--	--	--	2,889

associated with snowmelt, played an important role in the transport of suspended sediment in the Lower Valley. At Union Gap, Grandview, and Kiona, 50 to 64 percent of the total annual suspended sediment load in the 1988–89 WY was transported during this snowmelt period (table 8). Similarly, during this same period, the Naches River accounted for 63 percent of the total annual load. The intrasite variations in sediment loads between the snowmelt season and the winter season were large. For example, in the Naches River in the 1989 WY, the snowmelt season load was more than double the irrigation season load. Snowmelt affected runoff from a larger proportion of the land surface in the Naches River Subbasin than did the irrigation season release of water from the storage reservoirs.

The load at Union Gap represented a sizable portion (112 percent in 1988 WY and 89 percent in 1989 WY) of the load at Kiona (table 7). The range of values between years reflects the absence of an

Table 8. Summary statistics for the seasonal transport of suspended sediment loads at fixed sites, Yakima River Basin, Washington, 1988–89 water years.

[Mean daily suspended sediment loads are reported as tons per day; see table 3 for full site names]

	Percent of annual suspended sediment load				Mean daily suspended sediment load			
Site	Post-irrigation (Oct-Dec)	Winter (Jan-Mar)	Snowmelt (Apr-May)	Irrigation (Jun-Sep)	Post-irrigation (Oct-Dec)	Winter (Jan-Mar)	Snowmelt (Apr-May)	Irrigation (Jun-Sep)
Cle Elum	4	10	21	64	3	8	24	36
Umtanum	3	5	26	66	16	32	240	300
Naches	4	3	63	29	10	8	220	50
Union Gap	7	9	50	33	86	110	900	300
Sulphur Creek	3	9	45	43	10	32	230	110
Grandview	10	14	62	14	180	240	1,600	180
Kiona	9	13	64	15	110	160	1,200	140

appreciable snowmelt in 1988. In the 1988 WY, the suspended sediment load associated with snowmelt was about 3 times smaller than during snowmelt in the 1989 WY. The 1988–89 WY annual load at Kiona was smaller than the respective load at Grandview, located 25 miles upstream from Kiona. The sediment load ratio of Kiona to Grandview for the 1988–89 WYs was 0.84 and 0.69, respectively. The smaller annual loads at Kiona may have been the result of diversions to Kennewick Canal and Kiona Canal and (or) the net deposition of sediment in the reach between the sites. Large-streamflow conditions, like those occurring during February of 1996, would likely increase the ratio between the sites. In the Lower Valley, much of the suspended sediment load was governed by waterways carrying irrigation return flow to the main stem. For example, in Sulphur Creek Wasteway, the median suspended sediment concentration was 103 mg/L (fig. 11). While the annual mean daily streamflow at Sulphur Creek Wasteway for the 1988 WY was only 9 percent of that at Kiona, the annual mean daily suspended sediment load accounted for 38 percent of the load at Kiona (table 7).

Mass Balance During the July 1988 Synoptic Sampling

The dynamics of suspended sediment transport were studied by computing suspended sediment loads over 12 main stem reaches for the period of July 26–29, 1988 (table 9). For each reach, the values of load input/output from tributaries (tributary inflowing) and canal diversions (canal outflowing) were calculated. The load at the downstream site was then calculated by applying these inputs/outputs to the measured load at the upstream site. This calculated load was compared to the measured load at the downstream site, and the difference between the two loads was computed. This type of analysis is termed **mass balance,** and the smaller the difference between the measured load and the calculated load, the better the mass balance for the reach. For comparison, mass balance calculations were also made for streamflow, a relatively conservative measure. A positive difference between the measured and calculated suspended sediment load or streamflows implies that unmeasured contributions (from point or nonpoint sources and [or] resuspension of streambed sediment) to the measured load exist. A negative difference, however, implies that unaccountable losses (from suspended sediment deposition and [or] streamflow diversions) exist in the reach. Differences between the measured and calculated loads might also be due to short term temporal variability (not truly steady conditions), errors in measuring suspended sediment concentrations and streamflow, and unmeasured inflows, including ground-water seepage.

In the Kittitas Valley, the suspended sediment loads between Cle Elum (RM 183.1) and Umtanum (RM 140.4) increased by a factor of four (154 t/d), with no significant change in discharge (table 9). The largest tributary loads of suspended sediment

Table 9. Estimated mass balances for instantaneous streamflows and suspended sediment loads in the main stem, selected major tributaries, and canals, Yakima River Basin, Washington, July 26–29, 1988

[Difference, calculated subtracted from measured; **bold site name**, main stem site; →, tributary inflowing site; ←, canal diversions (canal outflowing site); --, not applicable; nd, no data; canal loads are calculated using suspended sediment concentrations in the Yakima River near the point of diversion; N, streamflow entitlement for a diversion canal; E, estimate; No., number]

		Streamflow (cubic feet per second [ft^3/s])					Suspended sediment load (tons per day)				
		Main stem					Main stem				
Site name	Yakima River mile	Measured	Calculated	Difference	Tributary inflowing	Canal outflowing	Measured	Calculated	Difference	Tributary inflowing	Canal outflowing
Kittitas Valley											
Yakima River below Keechelus Dam	214.4	841	--	--	--	--	nd	nd	nd	--	--
→Kachess River	203.5	--	--	--	872	--	--	--	--	nd	--
←Kittitas Main Canal at Diversion at Easton	202.5	--	--	--	--	1,120	--	--	--	--	2.4
→Cle Elum River below Cle Elum Lake	185.6	--	--	--	3,050	--	--	--	--	nd	--
Yakima River at Cle Elum	183.1	3,780	3,640	+140	--	--	51	nd	nd	--	--
→Teanaway River Below Forks near Cle Elum	176.1	--	--	--	37	--	--	--	--	.05	--
→Taneum Creek	166.1	--	--	--	8	--	--	--	--	--	--
←West Side Ditch	166.1	--	--	--	--	[1]105 N	--	--	--	--	4.5
Yakima River at Thorp Highway Bridge at Ellensburg	165.4	3,590	3,720	-130	--	--	155	46	+109	--	--
←Town Canal	161.3	--	--	--	--	[1]110 N	--	--	--	--	4.8
←Cascade Canal	160.3	--	--	--	--	[1]150 N	--	--	--	--	6.5
←Miscellaneous small diversions (each less than 30 ft^3/s)	160–155.5	--	--	--	--	[2]175	--	--	--	--	4.7 E
→Miscellaneous small irrigations returns (each less than 30 ft^3/s)	160–155.5	--	--	--	[2]170	--	--	--	--	24 E	--
→Manastash Creek	154.5	--	--	--	35 E	--	--	--	--	--	--
→Wilson Creek above Cherry Creek at Thrall	147.0	--	--	--	83	--	--	--	--	2.2	--
→Cherry Creek at Thrall	147.0	--	--	--	127	--	--	--	--	28	--
Mid Valley											
Yakima River at Umtanum	140.4	3,800	3,570	+230	--	--	205	193	+12	--	--
→Umtanum Creek	139.8	--	--	--	5 E	--	--	--	--	--	--
←Roza Canal	127.9	--	--	--	--	[1]1,920 E	--	--	--	--	103
←Selah/Moxee Canal	123.6	--	--	--	--	[1]80 N	--	--	--	--	4.3
Yakima River at Harrison Road Bridge near Pomona	121.7	1,800	1,800	0	--	--	83	98	-15	--	--
→Naches River near North Yakima	116.3	--	--	--	328	--	--	--	--	2.6	--
←Moxee Canal	115.9	--			--	[2]45 E	--			--	2.1
→Roza Power Plant Return Flow	113.3	--	--	--	[1]755 E	--	--	--	--	41	--
→Wide Hollow Creek near Mouth at Union Gap	107.4	--	--	--	26	--	--	--	--	.6	--
→Moxee Drain at Thorp Road near Union Gap [3]	107.3	--	--	--	79	--	--	--	--	128	--
Lower Valley											
Yakima River above Ahtanum Creek at Union Gap	107.3	2,940	2,940	0	--	--	172	253	-81	--	--
→Ahtanum Creek at Union Gap	106.9	--	--	--	7.1	--	--	--	--	.06	--
←Wapato Canal	106.7	--	--	--	--	[4]1,700 E	--	--	--	--	101
←Sunnyside Canal	103.8	--	--	--	--	[4]1,150 E	--	--	--	--	68

Table 9. Estimated mass balances for instantaneous streamflows and suspended sediment loads in the main stem, selected major tributaries, and canals, Yakima River Basin, Washington, July 26–29, 1988—Continued

[Difference, calculated subtracted from measured; **bold site name**, main stem site; ➜, tributary inflowing site; ←, canal diversions (canal outflowing site); --, not applicable; nd, no data; canal loads are calculated using suspended sediment concentrations in the Yakima River near the point of diversion; N, streamflow entitlement for a diversion canal; E, estimate; No., number]

Site name	Yakima River mile	Streamflow (cubic feet per second [ft^3/s])					Suspended sediment load (tons per day)				
		Main stem					Main stem				
		Measured	Calculated	Difference	Tributary inflowing	Canal outflowing	Measured	Calculated	Difference	Tributary inflowing	Canal outflowing
Lower Valley—Continued											
Yakima River at river mile 91 at Zillah	91.2	[5]163	97.1	+65.9	--	--	1.8	3.1	-1.3	--	--
➜East Toppenish Drain at Wilson Road near Toppenish	86.0	--	--	--	30	--	--	--	--	1.6	--
➜Sub-Drain No. 35 at Parton Road near Granger	83.2	--	--	--	34	--	--	--	--	.6	--
➜Granger Drain at mouth near Granger	82.8	--	--	--	49	--	--	--	--	55	--
Yakima River at Highway 223 Bridge above Marion Drain at Granger	82.7	282	276	+6	--	--	53	59	-6	--	--
➜Marion Drain at Indian Church Road at Granger	82.6	--	--	--	39	--	--	--	--	.7	--
➜Toppenish Creek at Indian Church Road near Granger	80.4	--	--	--	54	--	--	--	--	1.9	--
Yakima River below Toppenish Creek at river mile 78.1	78.1	428	375	+53	--	--	32	56	-24	--	--
➜Coulee Drain	77.0	--	--	--	28	--	--	--	--	nd	--
Yakima River at river mile 72 above Satus Creek near Sunnyside	72.4	513	456	+57	--	--	29	nd	nd	--	--
➜Satus Creek at gage at Satus	69.6	--	--	--	84	--	--	--	--	4.7	--
➜South Drain	69.3	--	--	--	[6]82	--	--	--	--	[6]31	--
➜Drainage Improvement District (DID) No. 7	65.1	--	--	--	[2]25 E	--	--	--	--	nd	--
➜Sulphur Creek Wasteway near Sunnyside	61.0	--	--	--	151	--	--	--	--	52	--
➜Satus Drain 303	60.2	--	--	--	[2]60	--	--	--	--	--	--
Yakima River at Euclid Bridge at river mile 55 near Grandview	55.0	972	915	+57	--	--	68	117	-49	--	--
← Chandler Canal at Bunn Road at Prosser	47.1	--	--	--	--	[7]808	--	--	--	--	57
Yakima River above Snipes Creek and Spring Creek near Whitstran	43.0	206	164	+42	--	--	6.1	11	-4.9	--	--
➜Spring Creek at mouth at Whitstran	41.8	--	--	--	24	--	--	--	--	9.1	--
➜Snipes Creek at mouth at Whitstran	41.8	--	--	--	33	--	--	--	--	4.7	--
➜Chandler Power Return	35.8	--	--	--	[1]527	--	--	--	--	40	--
← Kiona Canal	34.9	--	--	--	--	[1]23 N	--	--	--	--	1.7
➜Corral Canyon Creek at mouth near Benton	33.5	--	--	--	16	--	--	--	--	1.2	--
Yakima River at Kiona	29.9	854	783	+71	--	--	51	59	-8	--	--
← Columbia Canal	18	--	--	--	--	[1]100 E	--	--	--	--	5.9
← Richland Canal	18	--	--	--	--	[1]45 E	--	--	--	--	2.7
Yakima River at Van Geisan Bridge near Richland	8.4	706	709	-3	--	--	44	42	+2	--	--

[1]Don Schramm, Bureau of Reclamation, oral commun., June 28, 1994.

[2]Estimated streamflow (Bureau of Reclamation and Soil Conservation Service, 1974).

[3]The values reported for this site are the means of four daily measurements made from July 26-29, 1988.

[4]Daily mean streamflow for the period July 26-29, 1988 (Don Schramm, Bureau of Reclamation, oral commun., June 29, 1994).

[5]Streamflow in the Yakima River below the Parker diversion into Sunnyside Canal (river mile 103.7) ranged from 75 to 607 ft^3/s for the period July 26–29, 1988 (Don Schramm, Bureau of Reclamation, oral commun., June 29, 1994).

[6]Streamflow and suspended sediment were measured June 27, 1989.

[7]281 ft^3/s were diverted into the Kennewick Canal at the Chandler Power Return (river mile 35.8) [Don Schramm, Bureau of Reclamation, oral commun., June 28, 1994].

in this reach were from Cherry Creek (28 t/d), which flows into Wilson Creek before entering the Yakima River, and other small irrigation returns (estimated at 24 t/d collectively). A large portion (67 percent) of the increase in the measured load originated in the reach between Cle Elum and the Thorp Highway Bridge (RM 165.4). It is not known if the sediment deposition during the low streamflows in June and the subsequent resuspension during the high streamflows in July accounts for this increase in load.

In the Mid and Lower Valleys, the calculated loads generally exceeded the measured loads, indicating unmeasured losses—most likely resulting from sediment deposition. In the reach between RM 72 and Grandview (RM 55), the difference was -49 t/d; therefore, nearly 50 tons of suspended sediment may have been deposited in this reach on a daily basis during the 4-day July 1988 synoptic sampling. During this sampling, a delta of sediment was observed in the main stem at the mouth of Sulphur Creek Wasteway. The depositional character of the main stem in the Lower Valley results from the low streamflows and the main stem's gentle slopes and meandering channels. These depositional characteristics underscore the importance of the snowmelt period and winter storms as mechanisms for resuspending and transporting sediment from the Mid and Lower Valleys.

A large portion of the suspended sediment load entering the Mid and Lower Valley was from the east side tributaries and was attributable to terrain characteristics, irrigation practices, and erosive landscapes in proximity to the Yakima River. The Warden-Esquatzel soil association, present throughout the drainage basins of the east side tributaries, is characterized by highly erosive silt-loam soils and steep subbasin slopes (mostly 2 to 15 percent). When combined with rill irrigation practices, a high rate of erosion can occur. For example, Moxee Drain (RM 107.3) and Sulphur Creek Wasteway (RM 61) had respective suspended sediment loads of 128 and 52 t/d (table 9). In contrast, the west side tributaries have small subbasin slopes (mostly 0 to 2 percent) and soils with erosion potentials described as only slight to moderate (Rinella and others, 1999). The suspended sediment loads from west side tributaries in July 1988 were generally less than 5 t/d. A notable exception among west side tributaries, however, was South Drain (RM 69.3), which had a suspended sediment load of 31 t/d (table 9). This large load from South Drain can be attributed to sandy erosive soils and the frequent tillage and rill irrigation associated with the hop fields located close to South Drain (Dave Myra, Soil Conservation Service, Toppenish, Washington, oral commun., September 1992).

Implications for Water Resource Monitoring and Regulation

The major source of suspended sediment and turbidity in the Yakima River Basin was agricultural activity, and the major period of transport for suspended sediment in the main stem was the winter storms and snowmelt period. Significant contributions of suspended sediment to the main stem during the irrigation season came from Wilson Creek in the Kittitas Valley, Moxee Drain in the Mid Valley, and Granger Drain, Sulphur Creek Wasteway, and South Drain in the Lower Valley. Tillage processes commonly used in the basin leave the land in a state that is easily eroded. High rates of sediment transport to tributaries were generally associated with the growing of hops. Apple and pear orchards, however, have reduced erosion by using sprinkler irrigation and grassland covers.

The Moxee Drain at Thorp Road had suspended sediment concentrations ranging from 47 to 613 mg/L in the 1988–89 WY. These concentrations were among the highest recorded in the Yakima River Basin. In response to the high concentrations measured, the North Yakima Conservation District has worked with landowners in the Moxee Drain Subbasin to apply best management practices to irrigated land, dry cropland, and rangeland on 75 percent of the subbasin's 97,930 acres. Best management practices include using underground drip irrigation, which was shown to reduce sediment transport to almost zero from one hop farm in the Moxee Drain Subbasin, and straw mulching, which was also shown to be effective in minimizing erosion during irrigation.

Nutrients

By Ted R. Pogue, Jr., Gregory J. Fuhrer, *and* Kenneth A. Skach

Nutrients in the water column affect both human health and aquatic biota. Nutrients measured in this study of the Yakima River Basin were ammonia (filtered), ammonia plus organic nitrogen (equivalent to reduced nitrogen, unfiltered), nitrite plus nitrate (filtered), soluble reactive phosphorus (SRP, filtered/undigested), and total phosphorus (unfiltered). Total nitrogen, which is a calculated value equal to the sum of nitrite plus nitrate and ammonia plus organic nitrogen, is another important nutrient measure. All nutrient species were reported either as nitrogen or as phosphorus.

The Yakima River Basin surface waters were monitored for nutrient concentrations during the 1987–91 WY. Comparison of median total phosphorus and nitrite plus nitrate concentrations for the Yakima River during this period were made to mean values from the USGS Benchmark and National Stream Quality Accounting Network (NASQAN) sites, and to historic Yakima River data collected from 1974–81 WY (table 10). Benchmark sites monitored streams minimally affected by human activities, while NASQAN sites monitored the outflow of major river drainage basins in the United States. The historic Yakima River data were similar to the 1987–91 WY data. The median total phosphorus concentration (0.01 mg/L) at Cle Elum, a site in the upper basin minimally affected by human activities, was close to the reference median concentration (median of the mean concentrations) for the 38 Benchmark sites throughout the United States (0.03 mg/L) (Richard Alexander, U.S. Geological Survey, written commun., 1994). The median nitrite plus nitrate concentration at Cle Elum (0.02 mg/L), however, was an order of magnitude smaller than the reference median concentration (0.24 mg/L) for Benchmark sites. In contrast, median total phosphorus and nitrite plus nitrate concentrations at Kiona, near the terminus of the basin, were 0.13 and 1.1 mg/L, respectively. These concentrations were similar to reference median concentrations of total phosphorus and nitrite plus nitrate (0.17 and 0.71 mg/L, respectively) measured by NASQAN at the mouths of 354 United States rivers. Sulphur Creek Wasteway, which contained irrigation return flow, excess canal water, ground-water seepage, and municipal waste, had median concentrations of nitrogen and phosphorus similar to or larger than the 75th percentile of the mean reference concentrations at NASQAN sites (table 10). This was not unexpected, because NASQAN sites were designed to represent multiple land uses. An average of these sites would, therefore, be expected to have nutrient concentrations smaller than agricultural drainages like Sulphur Creek Wasteway.

Land Use and Land Type Effects

The distribution of nutrient concentrations in the Yakima River Basin varied with land use. Temporal or seasonal effects also are important for defining land use influence on water quality. For example, spring snowmelt on forest and rangeland, periods of winter storms on land of all uses, and summer irrigation on agricultural land can alter the effect of their associated runoff on water quality. To help understand the relations between land use and water quality, synoptic data were collected July 14–19, 1987, during the summer irrigation season. Rather than make land use assignments on the basis of land use near the sampling site, the predominant sources of water for each site were estimated on the basis of the land and water use of the basin upstream from the sampling location according to the following categories: forested, agricultural, rangeland, and urban.

Although forested and agricultural classifications represented large percentages of the streamflow, the associated nutrient concentrations varied greatly among sites (table 11). Tributaries with streamflows predominantly composed of agricultural runoff had concentrations of nutrients that generally exceeded those found in tributaries with streamflows predominantly composed of forest runoff. Total nitrogen concentrations, for example, ranged from <0.30 to 5.3 mg/L in agricultural tributaries and had a median concentration (1.4 mg/L) nearly three times that of forested tributaries. Total phosphorus concentrations ranged from 0.06 to 0.99 mg/L in agricultural tributaries and had a median concentration (0.18 mg/L) equal to six times that of forested tributaries.

In the Mid and Lower Valleys, the drainages to the Yakima River can generally be described as low gradient with high organic carbon, silty soils to

Table 10. Comparison of selected nutrient concentrations in surface waters of the Yakima River Basin (1987–91 water years) to historical data from the Yakima River Basin and to surface waters in the United States

[All values are reported as milligrams per liter as nitrogen or phosphorus; NASQAN; National Stream Quality Accounting Network; total phosphorus and ammonia plus organic (amm+organic) nitrogen analyses were performed on unfiltered water; SRP (soluble reactive phosphorus), nitrite plus nitrate, and ammonia analyses were performed on filtered water; NA, no data available for fixed sites; <, less than; —, no data available]

Nutrients	Yakima River Basin (1987–91 water years)					Yakima River Basin (1974–81 water years)[1]					Benchmark (1980–89 water years)[2]			NASQAN (1980–89 water years)[3]		
	Number of samples	Value at indicated percentile				Number of samples	Value at indicated percentile				Value at indicated percentile			Value at indicated percentile		
		25	50	75	90		25	50	75	90	25	50	75	25	50	75
	Yakima River at Cle Elum (river mile 183.1)					**Yakima River at Cle Elum (river mile 183.1)**					**Means of 38 sites**			**Means of 354 sites**		
Total phosphorus	45	<0.01	0.01	0.02	0.03	70	0.01	0.02	0.04	0.06	0.02	0.03	0.05	0.11	0.17	0.27
SRP	42	<.01	<.01	<.01	.01	72	<.01	<.01	.01	.01	—	—	—	—	—	—
Nitrite plus nitrate	[4]44	.01	.02	.06	.09	72	.02	.03	.04	.07	.18	.24	.33	.43	.71	1.1
Amm+organic nitrogen	45	<.20	<.20	<.20	.20	—	—	—	—	—	—	—	—	—	—	—
Ammonia	45	<.01	.01	.01	.02	—	—	—	—	—	—	—	—	—	—	—
	Sulphur Creek Wasteway near Sunnyside (river mile 61)					**Sulphur Creek Wasteway at McGee Road (river mile 61)**					**Means of 38 sites**			**Means of 354 sites**		
Total phosphorus	48	.20	.27	.34	.42	71	.22	.29	.42	.68	.02	.03	.05	.11	.17	.27
SRP	49	.10	.12	.17	.23	71	.11	.16	.19	.25	—	—	—	—	—	—
Nitrite plus nitrate	49	1.6	2.2	6.1	6.5	72	1.7	2.7	5.4	6.1	.18	.24	.33	.43	.71	1.1
Amm+organic nitrogen	46	.60	.80	1.2	1.8	—	—	—	—	—	—	—	—	—	—	—
Ammonia	48	.08	.17	.44	.65	—	—	—	—	—	—	—	—	—	—	—
	Yakima River at Kiona (river mile 29.9)					**Yakima River at Kiona (river mile 29.9)**					**Means of 38 sites**			**Means of 354 sites**		
Total phosphorus	46	.10	.13	.16	.25	96	.10	.13	.16	.21	.02	.03	.05	.11	.17	.27
SRP	47	.05	.07	.08	.10	96	.06	.08	.09	.11	—	—	—	—	—	—
Nitrite plus nitrate	47	.76	1.1	1.2	1.4	96	.54	.89	1.2	1.5	.18	.24	.33	.43	.71	1.1
Amm+organic nitrogen	45	.30	.40	.60	1.0	—	—	—	—	—	—	—	—	—	—	—
Ammonia	46	.02	.03	.05	.06	—	—	—	—	—	—	—	—	—	—	—
	Seven fixed sites					**NA**					**Means of 38 sites**			**Means of 354 sites**		
Total phosphorus	320	.03	.09	.15	.27	—	—	—	—	—	.02	.03	.05	.11	.17	.27
Nitrite plus nitrate	311	.33	.79	1.7	2.7	—	—	—	—	—	.18	.24	.33	.43	.71	1.1

[1]Rinella, McKenzie, and Fuhrer, 1992b.

[2]Richard Alexander, U.S. Geological Survey, written commun., 1994.

[3]Richard Alexander, U.S. Geological Survey, written commun., 1994.

[4]Two values reported as <0.1 were deleted to maintain a consistent minimum reporting level.

Table 11. Streamflow and nutrient concentrations in tributaries having predominantly forested and agricultural sources of water, Yakima River Basin, Washington, July 14–19, 1987

[Sites in the Mid and Lower Valleys were classified as east or west side tributaries on the basis of which side of the Yakima River the drainage was located; all nutrient concentrations are reported in milligrams per liter as nitrogen or phosphorus. Total nitrogen concentrations were calculated as the sum of nitrite plus nitrate and ammonia plus organic nitrogen; for this calculation, a less than (<) value for nitrite plus nitrate was treated as a zero except when both the ammonia plus organic nitrogen and nitrite plus nitrate concentrations were censored—then, <0.20 + <0.10 = <0.30 was used for the total nitrogen concentration; *, not applicable]

Yakima River mile	Site name	East or west side tributary	Streamflow (cubic feet per second)	Total nitrogen (calculated)	Ammonia, in filtered water	Ammonia plus organic nitrogen, in unfiltered water	Nitrite plus nitrate, in filtered water	Total phosphorus, in unfiltered water	Soluble reactive phosphorus, in filtered water
	Predominantly Forested Sources								
176.1	Teanaway River below Forks near Cle Elum	*	36	.30	<0.01	0.3	<0.10	0.01	<0.001
147.0	Naneum Creek near Ellensburg	*	14	.30	.02	.3	<.10	.05	.03
147.0	Wilson Creek above Cherry Creek at Thrall	*	110	1.1	.04	.7	.44	.22	.12
116.3	Naches River near North Yakima	West	660	.17	.01	.15	.02	.02	<.01
80.4	Toppenish Creek near Fort Simcoe	West	12	.50	.01	.5	<.10	.04	.027
69.9	Satus Creek below Dry Creek near Toppenish	West	16	.50	.02	.5	<.10	.02	.025
	Predominantly Agricultural Sources								
153.7	Currier Creek at Dry Creek Road at Ellensburg	*	24	.90	.04	.8	.10	.06	<.01
150.1	Unnamed drain 1.9 miles northwest of Thrall	*	1.8	.96	.02	.3	.66	.07	.04
147.0	Cherry Creek at Thrall	*	102	3.6	.07	1.1	2.5	.32	.21
147.0	Badger Creek at Badger Pocket Road and 4th Parallel Road	*	8.8	2.8	.02	.5	2.3	.23	.17
108.0	Unnamed drain at Walters Road at Moxee City	East	26	2.2	--	1.5	.70	.36	.14
107.4	Wide Hollow Creek near mouth at Union Gap	West	37	1.4	.04	<.1	1.4	.12	.10
107.3	Tributary to Moxee Drain at Bell Road	East	12	3.2	.03	.6	2.6	.21	.13
107.3	Moxee Drain at Thorp Road near Union Gap	East	79	3.6	.19	2.1	1.5	.35	.13
106.9	Ahtanum Creek at Union Gap	West	7.1	.85	.03	.4	.45	.12	.09
86.0	E Toppenish Drain at Wilson Road near Toppenish	West	16	2.6	.02	.5	2.1	.23	.17
83.2	Sub-Drain Number 35 at Parton Road near Granger	West	33	2.2	.25	.4	1.8	.15	.07
82.8	Granger Drain at mouth near Granger	East	51	4.5	.27	3.1	1.4	.51	.16
82.6	Unnamed drain at Hoffer Road near Wapato	West	1.4	1.0	.03	.7	.42	.12	.06
82.6	Unnamed drain at Branch Road at Ashue near Wapato	West	4.2	.60	.01	.6	<.10	.08	.05
82.6	Unnamed drain at Branch Road at Yethonat near Wapato	West	3.3	.94	<.01	.5	.44	.08	.07

Table 11. Streamflow and nutrient concentrations in tributaries having predominantly forested and agricultural sources of water, Yakima River Basin, Washington, July 14–19, 1987—Continued

[Sites in the Mid and Lower Valleys were classified as east or west side tributaries on the basis of which side of the Yakima River the drainage was located; all nutrient concentrations are reported in milligrams per liter as nitrogen or phosphorus. Total nitrogen concentrations were calculated as the sum of nitrite plus nitrate and ammonia plus organic nitrogen; for this calculation, a less than (<) value for nitrite plus nitrate was treated as a zero except when both the ammonia plus organic nitrogen and nitrite plus nitrate concentrations were censored—then, <0.20 + <0.10 = <0.30 was used for the total nitrogen concentration; *, not applicable]

Yakima River mile	Site name	East or west side tributary	Streamflow (cubic feet per second)	Total nitrogen (calculated)	Ammonia, in filtered water	Ammonia plus organic nitrogen, in unfiltered water	Nitrite plus nitrate, in filtered water	Total phosphorus, in unfiltered water	Soluble reactive phosphorus, in filtered water
	Predominantly Agricultural Sources—Continued								
82.6	Harrah Drain at Harrah Road at Harrah	West	21	5.3	1.3	2.0	3.3	0.38	0.21
82.6	Unnamed drain to Marion Drain near Harrah	West	5.4	3.0	.06	.6	2.4	.19	.07
82.6	Unnamed drain at Becker and Yost Roads	West	29	5.0	.47	2.0	3.1	.48	.19
82.5	Marion Drain at Indian Church Road near Granger	West	19	2.7	.20	.7	2.0	.10	.04
80.4	Drain at Evans Road near Mountain View High School	West	1.5	.50	.03	.5	<.10	.99	.07
80.4	Unnamed drain at Progressive Road near Harrah	West	44	1.0	.04	.8	.24	.43	.22
80.4	Unnamed Creek at Barkes Road near White Swan	West	18	1.0	.02	.4	.60	.13	.09
80.4	Tributary to Mill Creek at Tecumseh Road	West	1.3	<.30	<.01	<.2	<.10	.14	.10
80.4	Toppenish Creek at Indian Church Road near Granger	West	55	2.8	.02	.4	2.4	.13	.07
69.6	Satus Creek at gage at Satus	West	84	2.4	.01	.5	1.9	.15	.08
61.0	Sulphur Creek Wasteway near Sunnyside	East	240	.99	.12	.7	2.1	.37	.13
60.2	Satus Drain 303 at Highway 22 at Mabton	West	12	.86	.02	.7	1.6	.18	.06
41.0	Spring Creek and Snipes Creek near Whitstran	East	85	.99	.02	.2	.79	.19	.04
33.5	Corral Canyon Creek at mouth near Benton	East	19	2.3	.02	.5	1.8	.08	.03

the west, and high gradient with low organic carbon, sandy soils to the east. The median total nitrogen and total phosphorus concentrations during the July 1988 synoptic sampling for the west side tributaries were 1.0 and 0.13 mg/L, respectively, while the medians for the east side tributaries were 2.3 and 0.35 mg/L, respectively (table 11). Within each of these drainages, however, the specific crops and the methods of tillage and irrigation are important factors affecting the quality of the irrigation return flow.

Rangeland was likely an important land use category during periods of rainfall and runoff. During the summer, however, the contribution to streamflow from rangeland was small, and in terms of land use, its effect on water quality was insignificant; the same was true for the urban areas. Main stem sites also were sampled during the July 1987 synoptic sampling and, like the tributaries, had total nitrogen and total phosphorus concentrations that increased as the percentage of streamflow attributable to agricultural areas increased (fig. 15). Downstream from Zillah, the percentage of streamflow from forested areas decreased from about 80 percent to less than 40 percent, and then less than 30 percent downstream of Prosser. In contrast, the percent of streamflow from agricultural areas increased from less than 20 percent to about 55 percent, and then to about 65 percent downstream of Prosser. In the Mid and Lower Valleys, the single greatest source of nitrogen and phosphorus during the synoptic period was agricultural areas.

Spatial Distribution

During the 1987–91 WY, nutrient concentrations were measured at the seven fixed sites. Although small background concentrations were measured at the Cle Elum site (table 10), these nutrient concentrations tended to increase downstream. The largest median concentrations measured in the main stem were at Grandview and Kiona, where the median concentrations were 4 to 70 times those measured at Cle Elum (fig. 16). The maximum concentrations at Union Gap were sometimes larger than those measured at Umtanum and reflected inputs from agriculturally affected tributaries, like Wide Hollow Creek and Moxee Drain. Water from the Naches River, with median nutrient concentrations about one-third to one-half those at Umtanum, and the Roza power return flow, which carried water diverted from the Yakima River just downstream from Umtanum, diluted the high concentration inputs from Wide Hollow Creek, Moxee Drain, and the Yakima sewage treatment plant, resulting in decreased concentrations at Union Gap.

Downstream from Union Gap, most of the main stem water was diverted into the Wapato and Sunnyside Canals, leaving little water in the river at Parker. Downstream from this point, agricultural drains, such as Sulphur Creek Wasteway, contributed high nutrient concentrations to the main stem. Median concentrations in Sulphur Creek Wasteway were approximately twice those in the main stem at Grandview and Kiona, with the exception of the ammonia concentration, which was about three times larger (fig. 16). Compared to data previously published for the Yakima River (Rinella, McKenzie, and Fuhrer, 1992b), the spatial distribution of nutrient concentrations along the main stem indicated little or no change over time (table 10).

Several synoptic surveys were conducted to help define spatial water-quality conditions during specific hydrologic conditions. The synoptic surveys included several sites over a short time period (usually 4 to 5 days) during periods of relatively steady flow conditions. These data provided a "snapshot" of the water quality in the basin. Of these synoptic surveys, the irrigation season survey for the period of July 26–29, 1988, was of particular interest, because the streamflow was highly regulated to provide irrigation water. Although nutrient concentration patterns in the upper main stem during the irrigation season were similar to those described previously, the synoptic survey allowed closer inspection of downstream spatial variations in concentrations in the main stem and tributaries.

During the July 1988 synoptic sampling, several irrigation drains in the upper reach of the Yakima River contributed high nutrient concentrations to the main stem. For example, Wilson Creek and Cherry Creek, which merge prior to entering the main stem at RM 147, had total nitrogen and total phosphorus concentrations that were 7 to 25 times larger than those at Cle Elum (fig. 17). Downstream from the creeks, the

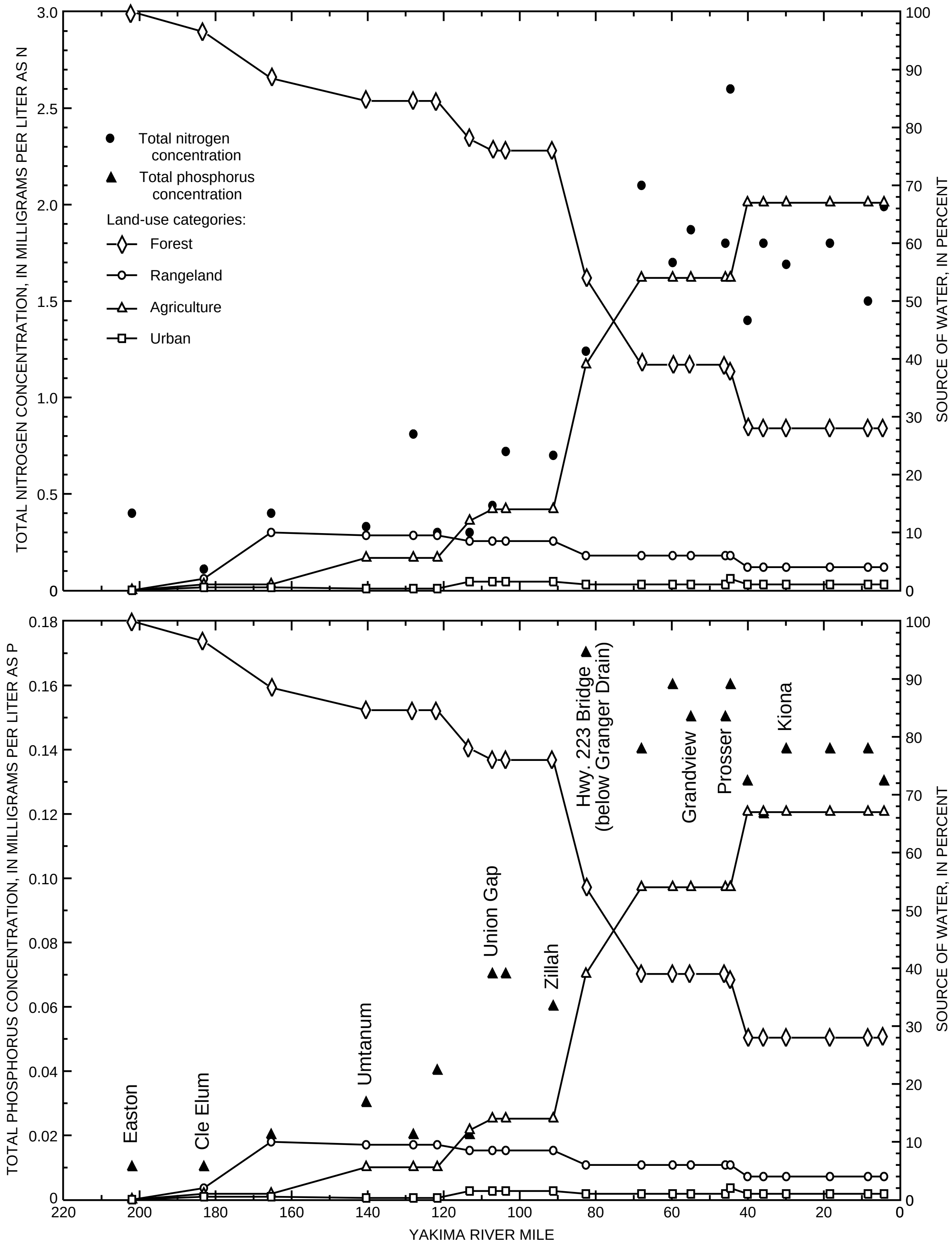


Figure 15. Associations between total nitrogen and total phosphorus concentrations and estimated sources of water in the Yakima River, Washington, July 14–19, 1987. (Total nitrogen concentrations are calculated as the sum of nitrite plus nitrate in filtered water and ammonia plus organic nitrogen in unfiltered water. Total phosphorus is determined from an unfiltered water sample. See table 3 for full site names. Hwy., Highway.)

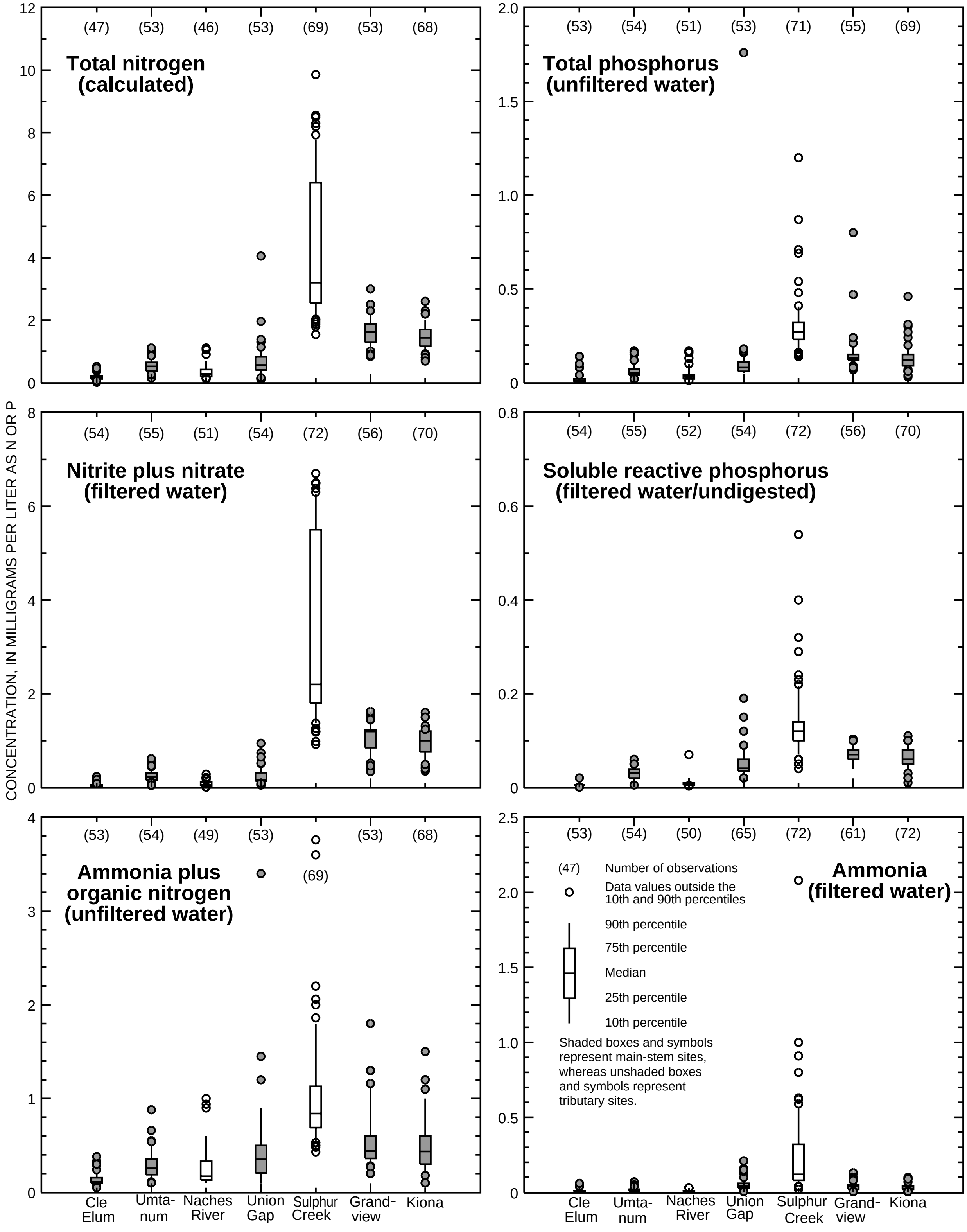


Figure 16. Statistical distributions of nutrient concentrations at fixed sites, Yakima River Basin, Washington, 1987–91 water years. (Concentrations lower than the minimum reporting level are shown as one-half their value. Total nitrogen concentrations are calculated as the sum of nitrite plus nitrate in filtered water and ammonia plus organic nitrogen in unfiltered water. See table 3 for full site names.)

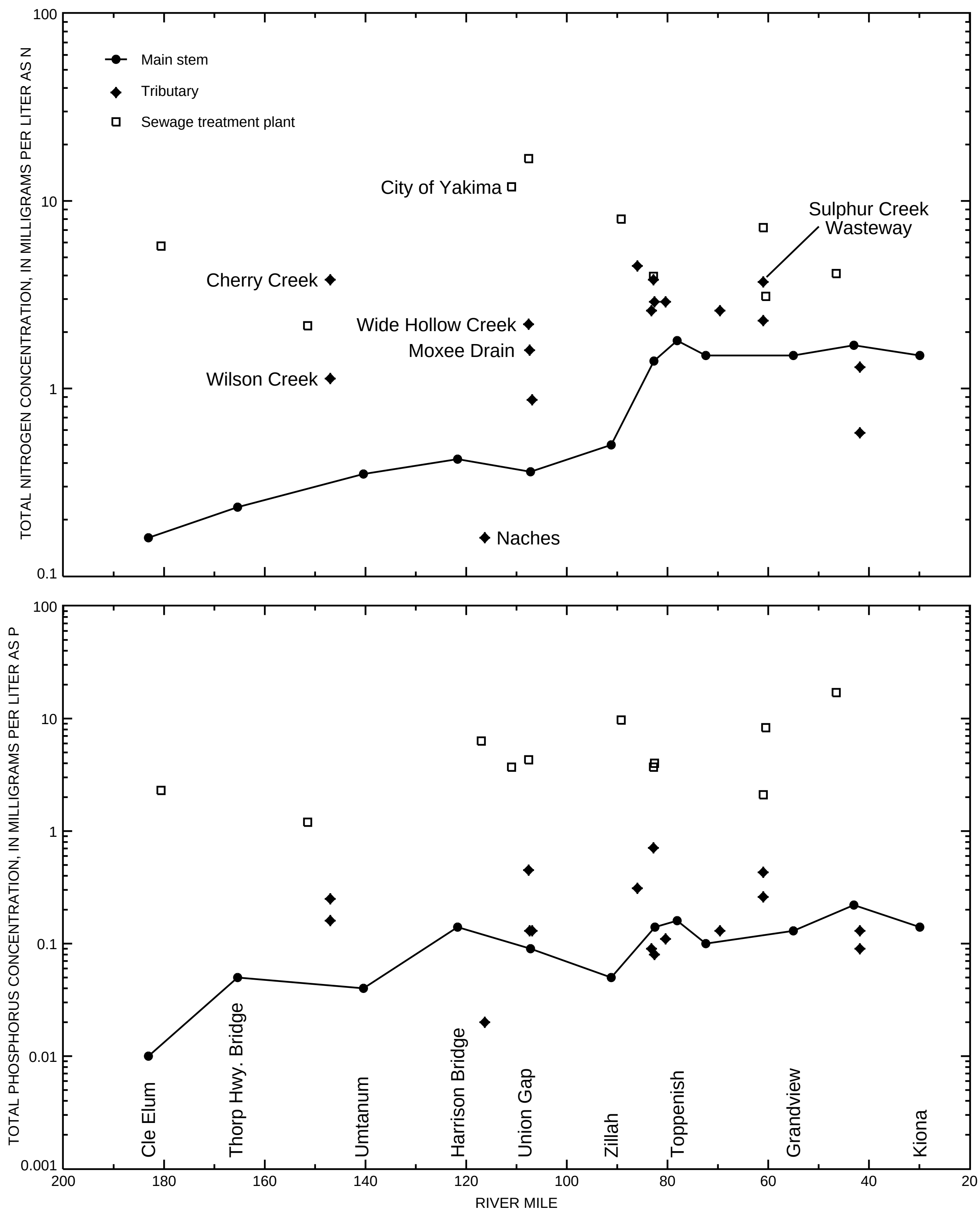


Figure 17. Downstream variation in total nitrogen and total phosphorus concentrations in the main stem, tributaries, and sewage treatment plants of the Yakima River, Washington, July 26–29, 1988. (See table 3 for full site names. Hwy., Highway.)

abundant streamflow in the upper reach of the main stem diluted these high nutrient concentrations. The total phosphorus concentration in the Yakima River at Thorp Highway Bridge at RM 165.4 (0.05 mg/L) seemed to be anomalously high and might reflect the sampling and analytical variability near the minimum reporting level (0.01 mg/L). During the irrigation season, high streamflows dominated the upper main stem due to release of water from upstream storage reservoirs. The July 1988 streamflow at Umtanum located downstream from the reservoirs, ranged from 2,780 to 4,130 ft^3/s, compared to a mean for the water year of 1,610 ft^3/s.

Downstream from Umtanum, the Roza Canal (RM 127.9) and the Selah/Moxee Canal (RM 123.6) diverted approximately one-half the flow of the main stem (approximately 2,000 ft^3/s). Between Umtanum and the Yakima River at Harrison Bridge (RM 121.7), total nitrogen and total phosphorus concentrations increased; however, this concentration increase lacks an obvious explanation. Farther downstream at Union Gap (RM 106.9), total nitrogen and total phosphorus concentrations decreased slightly. Sources of total nitrogen and total phosphorus entering the main stem above Union Gap were associated principally with effluents from the Yakima sewage treatment plant at RM 111 (11.9 and 3.7 mg/L, respectively) and agricultural return flows from Wide Hollow Creek at RM 107.4 (2.16 and 0.13 mg/L, respectively) and Moxee Drain at RM 107.3 (1.38 and 0.15 mg/L, respectively) (fig. 17). The streamflow inputs from the Roza power plant return and the relatively dilute Naches River, however, minimized the impact of these elevated sources on the main stem at Union Gap.

Below Union Gap, the Wapato (RM 106.7) and Sunnyside (RM 103.8) Canal diversions reduced the main stem streamflow to 163 ft^3/s in the Yakima River at Zillah (RM 91.2) during the July 1988 synoptic survey. The total nitrogen concentration in the Yakima River downstream from these diversions increased from 0.5 mg/L at Zillah to 1.8 mg/L in the Yakima River below Toppenish Creek (RM 78.1) (fig. 17). This concentration increase reflected the agricultural inputs from numerous creeks and agricultural drains, which accounted for approximately 75 percent of the flow in the lower main stem and whose concentrations were typified by the Sulphur Creek Wasteway (RM 61). Downstream from the Yakima River below Toppenish Creek, the total nitrogen concentrations remained relatively constant and ranged from 1.5 to 1.7 mg/L (fig. 17).

Patterns for total phosphorus concentrations were similar to total nitrogen concentrations in the reach below Union Gap, except at Zillah. The total phosphorus concentration actually dropped from 0.09 mg/L at Union Gap to 0.05 mg/L at Zillah, which was close to the concentration measured at Umtanum (fig. 17). The reduction of phosphorus was primarily in the form of SRP, which decreased from 0.04 mg/L at Union Gap to 0.01 mg/L at Zillah. Field observations at Zillah indicated a luxuriant community of periphytic algae, which are known to utilize SRP. Downstream of Zillah, the total phosphorus concentrations remained at or above 0.1 mg/L during the synoptic survey.

Temporal Variation

Nitrogen

Seasonal variations in total nitrogen concentrations in the Yakima River were primarily limited to the Lower Valley, downstream from Union Gap, where these variations had distinct seasonal patterns (fig. 18). These trends were primarily a function of nitrite plus nitrate, which generally accounted for 60 to 80 percent of the total nitrogen. During the post-irrigation and winter months (October through March), discharge from irrigation reservoirs was minimal and streamflow in the lower main stem, except during winter storms, was similar to streamflow during the irrigation season. The concentrations of nitrite plus nitrate and total nitrogen at Kiona remained high during the post-irrigation months and subsequently decreased with the flushing action of winter storms in the Lower Valley (fig. 19). Closure of the diversions also decreased the streamflow in the tributaries, which received much of their streamflow from excess canal water and irrigation return flow. During the October to March period, nitrite plus nitrate and total nitrogen concentrations increased in Sulphur Creek Wasteway (fig. 19). These high concentrations were the result of drainage from shallow ground water, overland runoff during winter storms, drainage from feedlots, point source discharges, and urban runoff. Estimates from the

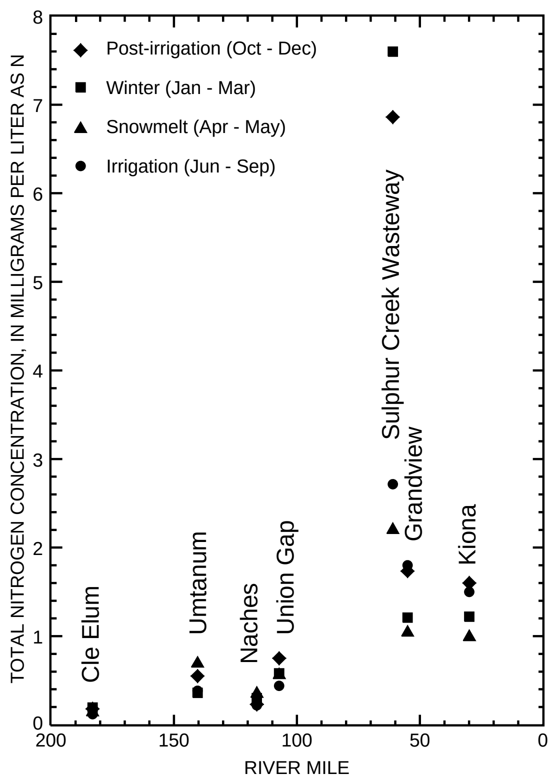


Figure 18. Median seasonal total nitrogen concentrations at selected sites, Yakima River Basin, Washington, 1987–91 water years. (To avoid statistical bias, only the first concentration per day was used. See table 3 for full site names.)

Sunnyside sewage treatment plant, however, showed that effluent nitrite plus nitrate concentration and streamflow (2.2 mg/L and 3.1 ft^3/s, respectively, measured July 26, 1988) were too small to have strongly influenced the total nitrogen concentrations in Sulphur Creek Wasteway. The presence of high nitrogen concentrations in shallow ground water was likely a result of fertilizer applications (agricultural and limited urban), manure applications (liquid and solid), septic tank waste, and atmospheric deposition.

During the snowmelt season (April and May), melting snow in conjunction with spring rains caused the highest streamflows in the 1988 WY. For example, the highest instantaneous discharge (5,880 ft^3/s) and the lowest nitrite plus nitrate concentrations (0.48 mg/L) of the year at Kiona were measured during April 17, 1988, snowmelt runoff (fig. 19). Although nitrite plus nitrate and total nitrogen concentrations responded similarly in the lower main stem, exceptions were found. Exceptions during

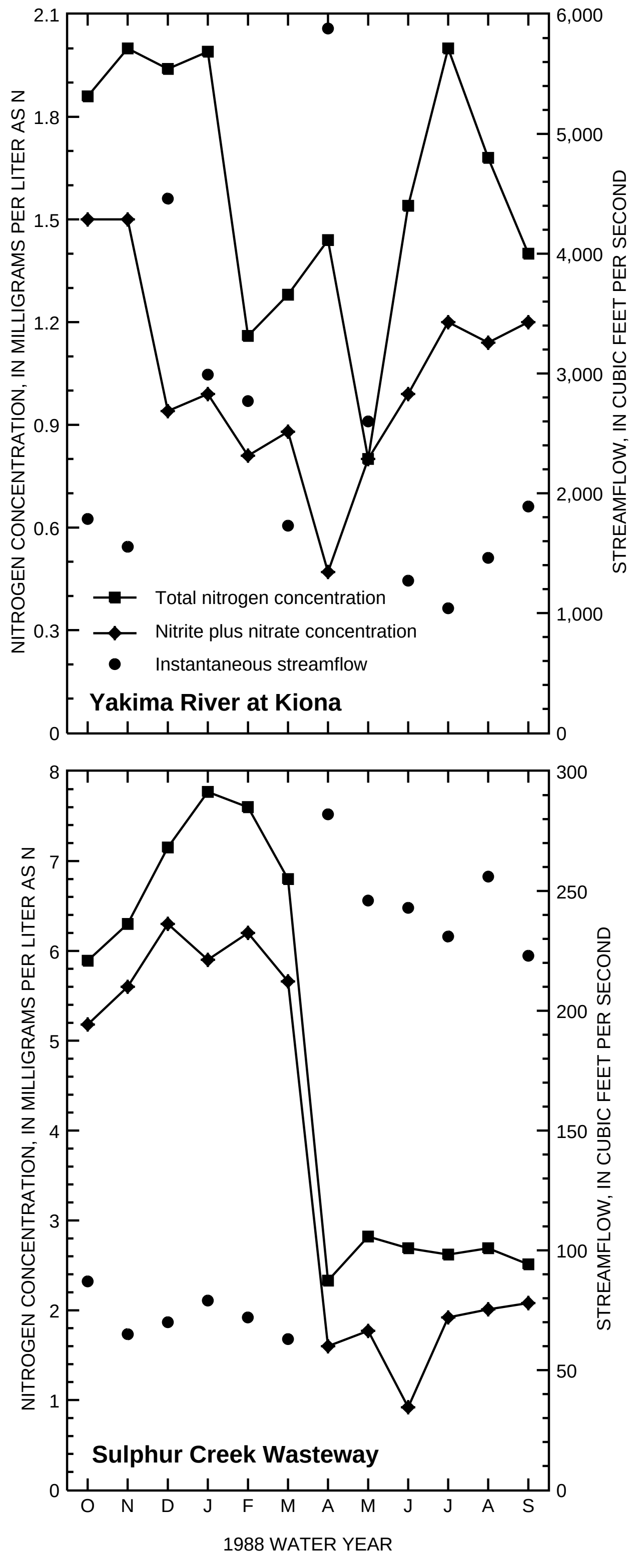


Figure 19. Total nitrogen and nitrite plus nitrate concentrations in the Yakima River at Kiona and Sulphur Creek Wasteway near Sunnyside, Yakima River Basin, Washington, 1988 water year.

the October to May period were due to increases in ammonia plus organic nitrogen concentrations that coincided with increases in suspended sediment concentrations in the main stem from resuspended streambed sediment during winter and spring storms (fig. 14). These ammonia plus organic nitrogen concentrations generally accounted for more than one-half of the total nitrogen at Kiona during these storms (52 percent in December, 50 percent in January, and 67 percent in April). In Sulphur Creek Wasteway, similar increases in the total nitrogen concentrations during the winter months were also the result of increased ammonia plus organic nitrogen concentrations (fig 19). These high winter concentrations of ammonia plus organic nitrogen were likely caused by overland runoff from dairies and feedlots during precipitation events and the land application of manure.

Irrigation begins in the Yakima River Basin in late March to early April. Excess irrigation canal water, along with irrigation return flow, increased flows in Sulphur Creek Wasteway and other agriculturally influenced tributaries in the Lower Valley. This increased streamflow diluted nitrite plus nitrate and total nitrogen concentrations in Sulphur Creek Wasteway (fig. 19). In contrast, the nitrite plus nitrate and total nitrogen concentrations increased at Kiona during the irrigation season (June through September). The high total nitrogen concentration (2.0 mg/L) relative to the nitrite plus nitrate concentration (1.2 mg/L) in July appeared to be related to the conversion of nitrate and nitrite to organic nitrogen (by algae) and to agricultural activity in the lower basin. Large concentrations of ammonia plus organic nitrogen were also measured in agricultural drains during the irrigation season.

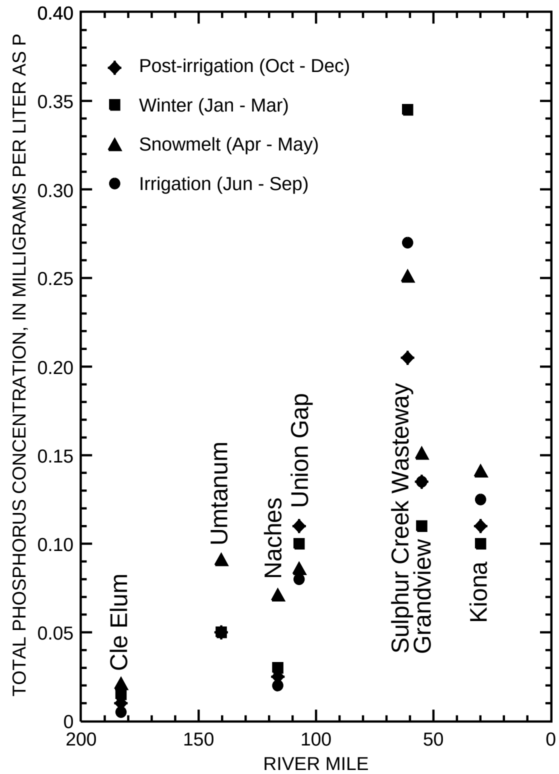


Figure 20. Median seasonal total phosphorus concentrations at selected sites, Yakima River Basin, Washington, 1987–91 water years. (To avoid statistical bias, only the first concentration per day was used. See table 3 for full site names.)

Phosphorus

The highest median concentrations of total phosphorus in the main stem were generally measured during the snowmelt season (fig. 20). At Union Gap, however, streamflow from the Naches River, which had low total phosphorus concentrations (median of 0.07 mg/L), diluted the main stem total phosphorus concentration, resulting in a median concentration of 0.09 mg/L. This dilution effect also was exhibited during the irrigation season. The post-irrigation and winter median concentrations of total phosphorus at Union Gap were slightly elevated (fig. 20), and may have been due to a combination of decreased streamflow and, subsequently, less dilution of the effluent discharged from the Yakima sewage treatment plant, stormwater runoff, and ground-water seepage. The highest median concentration of total phosphorus in Sulphur Creek Wasteway (0.34 mg/L) was measured during the winter months when streamflow was low (fig. 20). The seasonal variations in the total phosphorus concentrations in Sulphur Creek Wasteway were likely the result of seasonal variations in effluent from the Sunnyside sewage treatment plant, runoff from feedlots, and ground-water seepage.

An important factor controlling total phosphorus concentrations in the surface waters of the Yakima River Basin was suspended sediment concentration. A large portion of the total phosphorus concentration, particularly during storms, was in the form of sediment-sorbed phosphorus (total phosphorus minus SRP). For example, high concentrations of sorbed phosphorus were measured during erosive storms and snowmelt at Kiona (fig. 21). During the April 1988 storm event, the sorbed phosphorus accounted for 81 percent of the total phosphorus (0.27 mg/L). SRP concentrations at Kiona showed little temporal variability during the 1988 WY (fig. 21).

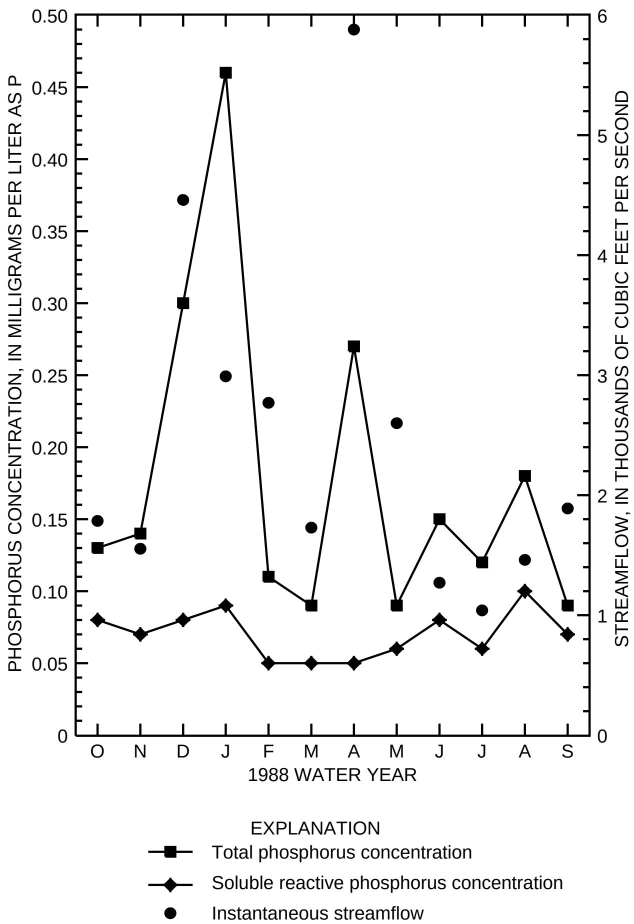


Figure 21.Total phosphorus and soluble reactive phosphorus concentrations in the Yakima River at Kiona, Yakima River Basin, Washington, 1988 water year.

SRP is important because it can be the limiting nutrient in eutrophication processes. Although peak total phosphorus concentrations were measured during winter storms and snowmelt months (fig. 21), these concentrations also were associated with high suspended sediment concentrations, high streamflows, and cool water temperatures, making eutrophication less likely. During the irrigation season, however, more favorable conditions for eutrophication existed in the Lower Valley, including warm water temperatures, low streamflow, moderate suspended sediment concentrations, and SRP concentrations between 0.05 and 0.1 mg/L. Although conditions conducive to eutrophication existed in the lower main stem, measurements of phytoplankton density and biovolume on July 10, 1992 and September 17, 1992 did not indicate eutrophication in the water column. The phytoplankton densities at Kiona (640 counts/milliliter in July and 450 counts/milliliter in September) were low in comparison with the moderate densities in the Willamette River near Corvallis (800 to 1,800 counts/milliliter; Jim Sweet, Aquatic Analysts, oral commun., September 19, 1994), a location of similar hydrologic regime. The lower counts at Kiona indicated that stream turbidity may have been inhibiting phytoplankton growth. If turbidity were to significantly decrease, increased sunlight penetration in the water column could increase eutrophication in the lower Yakima River and result in unacceptable levels of dissolved oxygen, pH, and aquatic growth.

Monthly and Annual Loads

Monthly and annual mean daily nutrient loads were calculated using ESTIMATOR (see Study Description section for an explanation of the program). These monthly loads were then summarized by season (table 12). Because of the need for daily streamflow measurements and monthly and storm event measurements of nutrient concentrations, these loads were calculated only at fixed sites. Annual loads for the Yakima River Basin showed the effects of increased annual precipitation during the study period, and in all cases, the annual loads for the 1989 WY were equal to or larger than those for the 1988 WY (table 12).

Large loads of sediment sorbed phosphorus (total phosphorus minus SRP) and ammonia plus organic nitrogen generally coincided with high streamflows associated with the snowmelt season. During the 1988–89 WY at Kiona, the largest seasonal mean daily streamflow and suspended sediment load (3,620 ft^3/s and 1,200 t/d, respectively; tables 1 and 8) were measured during the snowmelt season. The largest sorbed phosphorus and ammonia plus organic nitrogen loads were also measured during snowmelt (table 12). During the post-irrigation, winter, and irrigation seasons, the mean daily streamflows (table 1) and suspended sediment loads (table 8) in the Lower Valley remained relatively small and less variable than during the snow-

Table 12. Summary statistics for the seasonal transport of nutrient loads at fixed sites, Yakima River Basin, Washington, 1988–89 water years

[See table 3 for full site names; the sum of the seasonal percentages may not equal 100 due to rounding]

Site	Seasonal mean-daily nutrient load, in pounds per day (percent of annual load)									
	1988 water year					1989 water year				
	Post-irrigation (Oct-Dec)	Winter (Jan-Mar)	Snowmelt (Apr-May)	Irrigation (Jun-Sep)	Annual	Post-irrigation (Oct-Dec)	Winter (Jan-Mar)	Snowmelt (Apr-May)	Irrigation (Jun-Sep)	Annual
Ammonia plus organic nitrogen										
Cle Elum	140 (5)	320 (12)	470 (11)	1,500 (72)	690 (100)	340 (8)	440 (11)	1,400 (23)	1,800 (60)	1,000 (100)
Umtanum	740 (7)	1,400 (13)	3,200 (20)	4,700 (60)	2,600 (100)	1,200 (8)	1,900 (13)	7,100 (32)	5,300 (48)	3,700 (100)
Naches	550 (11)	620 (12)	3,000 (38)	1,400 (36)	1,300 (100)	730 (12)	670 (11)	4,000 (44)	1,500 (33)	1,500 (100)
Union Gap	3,100 (16)	3,300 (17)	7,000 (24)	6,000 (42)	4,800 (100)	4,400 (17)	4,400 (17)	12,000 (31)	6,400 (33)	6,400 (100)
Sulphur Creek	440 (13)	760 (22)	1,400 (27)	950 (37)	850 (100)	470 (12)	700 (18)	1,700 (30)	1,000 (35)	940 (100)
Grandview	3,900 (23)	4,000 (23)	6,400 (25)	3,900 (30)	4,300 (100)	5,400 (19)	5,300 (18)	17,000 (40)	4,500 (21)	7,100 (100)
Kiona	3,500 (19)	4,400 (24)	8,100 (29)	3,800 (28)	4,600 (100)	4,400 (16)	4,300 (15)	19,000 (45)	4,000 (19)	7,100 (100)
Sediment-sorbed phosphorus (total phosphorus minus soluble reactive phosphorus)										
Cle Elum	5.7 (3)	31 (16)	35 (12)	99 (69)	48 (100)	25 (8)	48 (14)	140 (28)	120 (48)	84 (100)
Umtanum	32 (3)	170 (14)	360 (21)	510 (59)	290 (100)	130 (7)	250 (13)	1,000 (36)	600 (43)	470 (100)
Naches	46 (8)	58 (10)	440 (52)	140 (33)	140 (100)	70 (9)	65 (8)	680 (57)	170 (28)	200 (100)
Union Gap	300 (11)	450 (17)	1,100 (27)	770 (38)	670 (100)	460 (13)	640 (18)	2,300 (43)	860 (32)	890 (100)
Sulphur Creek	34 (6)	110 (18)	320 (36)	200 (44)	150 (100)	42 (6)	89 (12)	450 (40)	220 (39)	190 (100)
Grandview	560 (21)	650 (24)	1,300 (32)	550 (27)	670 (100)	920 (16)	1,000 (18)	4,400 (52)	650 (16)	1,400 (100)
Kiona	580 (25)	490 (21)	1,200 (34)	430 (24)	590 (100)	700 (16)	650 (14)	3,700 (56)	390 (12)	1,100 (100)
Nitrite plus nitrate										
Cle Elum	38 (6)	95 (15)	80 (8)	340 (71)	160 (100)	140 (14)	160 (15)	300 (19)	390 (50)	260 (100)
Umtanum	1,100 (13)	1,300 (15)	2,300 (18)	3,200 (51)	2,100 (100)	1,500 (16)	1,500 (15)	3,000 (21)	3,400 (47)	2,400 (100)
Naches	350 (27)	310 (24)	400 (21)	260 (27)	320 (100)	440 (30)	330 (22)	500 (22)	270 (24)	370 (100)
Union Gap	2,200 (20)	2,600 (24)	3,500 (22)	3,000 (37)	2,700 (100)	3,200 (24)	3,500 (25)	4,900 (24)	3,000 (29)	3,400 (100)
Sulphur Creek	2,600 (26)	2,300 (23)	2,300 (15)	2,500 (33)	2,500 (100)	2,600 (26)	2,300 (23)	2,400 (16)	2,600 (35)	2,500 (100)
Grandview	13,000 (30)	11,000 (25)	9,300 (14)	9,700 (29)	11,000 (100)	15,000 (32)	12,000 (25)	12,000 (17)	10,000 (28)	12,000 (100)
Kiona	13,000 (33)	11,000 (27)	9,200 (15)	8,600 (29)	10,000 (100)	15,000 (32)	12,000 (25)	12,000 (17)	8,900 (25)	12,000 (100)
Soluble reactive phosphorus										
Cle Elum	5.5 (6)	16 (17)	20 (14)	44 (64)	23 (100)	14 (10)	21 (14)	54 (25)	53 (49)	36 (100)
Umtanum	110 (11)	130 (12)	300 (19)	460 (59)	260 (100)	150 (13)	150 (12)	380 (21)	480 (53)	300 (100)
Naches	29 (16)	38 (20)	96 (35)	41 (30)	46 (100)	37 (17)	40 (18)	120 (36)	44 (27)	55 (100)
Union Gap	520 (21)	600 (24)	720 (19)	650 (34)	630 (100)	660 (23)	700 (24)	870 (20)	670 (31)	710 (100)
Sulphur Creek	77 (16)	99 (20)	160 (22)	140 (39)	120 (100)	81 (17)	91 (19)	180 (25)	150 (42)	120 (100)
Grandview	810 (28)	820 (28)	750 (17)	600 (27)	730 (100)	940 (27)	920 (26)	1,100 (21)	650 (25)	870 (100)
Kiona	790 (28)	770 (27)	750 (18)	570 (27)	710 (100)	900 (27)	870 (26)	1,200 (24)	580 (23)	840 (100)

melt season; additionally, they coincided with small and minimally varying sorbed phosphorus and ammonia plus organic nitrogen loads (table 12).

Loads of sorbed phosphorus and ammonia plus organic nitrogen generally increased downstream in the main stem of the Yakima River (table 12). During the 1988 and 1989 WYs, the smallest annual loads of sorbed phosphorus (48 and 84 lb/day [pounds per day], respectively) were measured at Cle Elum and the largest (670 and 1,400 lb/day, respectively) were at Grandview. For ammonia plus organic nitrogen, the smallest loads (690 and 1,000 lb/day, respectively) were also at Cle Elum, but the largest was measured at Union Gap (4,800 lb/day) in the 1988 WY and at Grandview and Kiona (both 7,100 lb/day) in the 1989 WY. The presence of larger loads nearer the terminus of the basin in the 1989 WY was probably a result of higher streamflows and suspended sediment concentrations in the 1989 WY. The annual mean streamflow for the 1989 WY was nearly 23 percent larger than for the 1988 WY.

"Dissolved nutrients" are operationally defined as nutrients measured in filtered water samples (nitrite plus nitrate and SRP). In the Kittitas Valley at Cle Elum, dissolved nutrient loads were small and generally controlled by streamflow (tables 1 and 12). Even though mean daily dissolved nutrient loads for the 1988–89 WY increased in the reach from Cle Elum to Umtanum by 8 to 13 fold for nitrite plus nitrate and SRP, these loads were small compared to those near the terminus of the basin. The 1988–89 WY annual loads for Umtanum were about 20 percent of those at Kiona for nitrite plus nitrate and 36 percent of those at Kiona for SRP (table 12).

Although increases in streamflow are commonly associated with increases in loads, the irrigation season loads and the winter loads of nitrite plus nitrate and SRP did not follow this pattern at Union Gap and Naches. Instead, the respective loads remained similar between seasons, while the irrigation season streamflows increased in comparison to the winter streamflows. During the 1988 WY, for example, the irrigation season streamflow (3,083 ft^3/s) at Union Gap was more than twice that of winter, yet the respective SRP and nitrite plus nitrate loads differed by less than 14 percent—similar findings were noted during the 1989 WY (table 12). This similarity in loads may be indicative of a somewhat constant source of dissolved nutrients, such as ground-water seepage and point sources, that is less diluted during the winter (larger concentrations, lower streamflow) and more diluted during the irrigation season (smaller concentrations, higher streamflow).

The Kittitas and Mid Valleys were important sources of SRP, and loads from those basins were comparable to inputs from the Lower Valley. For example, the annual loads for the 1988 and 1989 WYs at Union Gap were 89 and 84 percent of the respective annual loads at Kiona (table 12). During the irrigation season, most of the load at Union Gap was diverted for irrigation, and most of the load at Kiona during this period was derived from the irrigation return flow to the lower main stem. In contrast, the annual nitrite plus nitrate loads for the 1988–89 WY increased only minimally from Umtanum to Union Gap (table 12). The annual load of nitrite plus nitrate during the 1988 and 1989 WYs at Union Gap were only 27 and 28 percent of the respective loads at Kiona, indicating that the Lower Valley was the major contributor of nitrite plus nitrate—the Lower Valley also remained a major contributor during the irrigation season.

In the Lower Valley, the mean daily nitrite plus nitrate loads among the seasons were fairly evenly distributed throughout the year. The similarity among loads was most notable at Sulphur Creek, where the loads differed among the seasons during the 1988–89 WY by a factor no greater than two (table 12). Figure 19 illustrates the inverse relation between streamflow and nitrite plus nitrate concentrations that resulted in the even load distribution. The increase in nitrite plus nitrate concentrations during the post-irrigation and winter seasons was significant because it suggests a ground-water connection. Apart from rare winter storms, the Sulphur Creek Basin received minimal overland runoff during the post-irrigation and winter seasons, yet the loads among seasons remained comparable. The principal nitrogen sources were probably ground-water infiltration of nitrogen based fertilizers, spills from feedlots, land based application of solid and liquid forms of manure, urban activities (including a sewage treatment plant), septic tanks, and atmospheric deposition.

In contrast, the mean daily SRP loads at Sulphur Creek varied among seasons with variations in streamflow. SRP loads during the 1988 and 1989 WYs were larger during the higher streamflows of the snowmelt and irrigation seasons, both by a factor of two (table 12). This relation with streamflow suggests that SRP loads probably were affected by the same sources affecting nitrite plus nitrate loads, as well as overland runoff from irrigated agriculture. Quantification of the loading from overland runoff during the irrigation season in relation to the loading to Sulphur Creek via groundwater seepage was not within the scope of this investigation.

Mass Balance during the July 1988 Synoptic Sampling

The dynamics of nutrient transport were studied by computing total nitrogen and phosphorus loads over 12 main stem reaches for the period of July 26–29, 1988 (tables 13 and 14). For each reach, the values of load input/output from tributaries (tributary inflowing) and canal diversions (canal outflowing) were calculated. The load at the downstream site was then calculated by applying these inputs/outputs to the measured load at the upstream site. This calculated load was compared to the measured load at the downstream site, and the difference between the two loads was computed. This type of analysis is termed **mass balance,** and the smaller the difference between the measured and calculated loads, the better the mass balance for the reach. For comparison, mass balance calculations also were made for streamflow, a relatively conservative measure. A positive difference between the measured and calculated nutrient loads or streamflows implies that unmeasured contributions (from point or nonpoint sources and [or] resuspension of streambed sediment) to the measured load exist. A negative difference, however, implies that unaccountable losses (from suspended sediment deposition and [or] streamflow diversions) exist in the reach. Differences between the measured and calculated loads might also be due to short term temporal variability (not truly steady conditions), errors in measuring nutrient concentrations and streamflow, and unmeasured inflows, including groundwater seepage.

In the Kittitas Valley, the loads between Cle Elum (RM 183.1) and Umtanum (RM 140.4) increased by more than a factor of two (3,900 lb/day) for total nitrogen and by a factor of four (620 lb/day) for total phosphorus, with no significant change in discharge (tables 13 and 14). These large increases were due mainly to the inputs from Wilson and Cherry Creeks (RM 147.0), as well as from other irrigation drains. Contributions from Cherry Creek alone accounted for 67 percent of the measured increase in the total nitrogen load and 27 percent of the total phosphorus increase between Cle Elum and Umtanum. Additionally, point sources such as the Ellensburg sewage treatment plant (RM 151.5), which accounted for about 7 percent of the increase in the total phosphorus load, and a feedlot contributed to the main stem load (tables 13 and 14).

In the Mid Valley, the Naches River (RM 116.3), Roza power plant return (RM 113.3), and the Yakima sewage treatment plant (RM 111.0) appeared to be the major sources of total nitrogen (6,900; 1,400; and 1,600 lb/day, respectively) and total phosphorus (440, 160, and 510 lb/day, respectively) between Umtanum and Union Gap (RM 107.3) (tables 13 and 14). Moxee Drain (RM 107.3) was also a major source of total nitrogen (700 lb/day) and total phosphorus (120 lb/day). In the Lower Valley, the Wapato (RM 106.7) and Sunnyside (RM 103.8) Canals diverted approximately 97 percent of the main stem streamflow at Union Gap, and, therefore, reduced the main stem total nitrogen and total phosphorus loads similarly. Total nitrogen and total phosphorus loads at Zillah (RM 91.2), below the Wapato and Sunnyside Canal diversions, were less than 10 percent of the loads measured at Union Gap (tables 13 and 14). Therefore, the direct effect of the Kittitas and Mid Valley

Table 13. Estimated mass balances for instantaneous streamflows and total nitrogen loads in the main stem, selected major tributaries, and canals, Yakima River Basin, Washington, July 26–29, 1988

[Difference, calculated subtracted from measured; **bold site name**, main stem site; →, tributary inflowing site; ←, canal outflowing site; --, not applicable; nd, no data; canal loads are calculated using total nitrogen concentrations in the Yakima River near the point of diversion; N, streamflow entitlement for a diversion canal; E, estimate; No., number; loads in parentheses are not included in the calculations of main stem load]

Site name	Yakima River mile	Streamflow (cubic feet per second [ft^3/s])					Total nitrogen load (pounds per day)				
		Main stem					Main stem				
		Measured	Calculated	Difference	Tributary inflowing	Canal outflowing	Measured	Calculated	Difference	Tributary inflowing	Canal outflowing
Kittitas Valley											
Yakima River below Keechelus Dam	214.4	841	--	--	--	--	nd	nd	nd	--	--
→Kachess River	203.5	--	--	--	872	--	--	--	--	nd	--
←Kittitas Main Canal at Diversion at Easton	202.5	--	--	--	--	1,120	--	--	--	--	nd
→Cle Elum River below Cle Elum Lake	185.6	--	--	--	3,050	--	--	--	--	nd	--
Yakima River at Cle Elum	183.1	3,780	3,640	+140	--	--	[1]3,300	nd	nd	--	--
→Cle Elum sewage treatment plant	180.6	--	--	--	1.0	--	--	--	--	30	--
→Teanaway River Below Forks near Cle Elum	176.1	--	--	--	37	--	--	--	--	[2]59	--
→Taneum Creek	166.1	--	--	--	8	--	--	--	--	[3]6	--
←West Side Ditch	166.1	--	--	--	--	[4]105 N	--	--	--	--	91
Yakima River at Thorp Highway Bridge at Ellensburg	165.4	3,590	3,720	-130	--	--	4,500	3,304	+1,196	--	--
←Town Canal	161.3	--	--	--	--	[4]110 N	--	--	--	--	140
←Cascade Canal	160.3	--	--	--	--	[4]150 N	--	--	--	--	190
←Miscellaneous small diversions (each less than 30 ft^3/s)	160–155.5	--	--	--	--	[5]175	--	--	--	--	370 E
→Miscellaneous small irrigation returns (each less than 30 ft^3/s)	160–155.5	--	--	--	[5]170	--	--	--	--	2,300 E	--
→Manastash Creek	154.5	--	--	--	35 E	--	--	--	--	[6]130 E	--
→Ellensburg sewage treatment plant	151.5	--	--	--	6.5	--	--	--	--	75	--
→Wilson Creek above Cherry Creek at Thrall	147.0	--	--	--	83	--	--	--	--	510	--
→Cherry Creek at Thrall	147.0	--	--	--	127	--	--	--	--	2,600	--
Mid Valley											
Yakima River at Umtanum	140.4	3,800	3,580	+220	--	--	7,200	9,415	-2,215	--	--
→Umtanum Creek	139.8	--	--	--	5 E	--	--	--	--	[3]5 E	--
←Roza Canal	127.9	--	--	--	--	[4]1,920 E	--	--	--	--	3,600 E
←Selah/Moxee Canal	123.6	--	--	--	--	[4]80 N	--	--	--	--	150
Yakima River at Harrison Road Bridge near Pomona	121.7	1,800	1,800	+0	--	--	4,100	3,455	+645	--	--
→Selah sewage treatment plant	117.0	--	--	--	1.6	--	--	--	--	100	--
→Naches River near North Yakima	116.3	--	--	--	328	--	--	--	--	6,900	--
←Moxee Canal	115.9	--	--	--	--	[5]45 E	--	--	--	--	230 E
→Roza Power Plant Return Flow	113.3	--	--	--	[4]755 E	--	--	--	--	1,400 E	--

Table 13. Estimated mass balances for instantaneous streamflows and total nitrogen loads in the main stem, selected major tributaries, and canals, Yakima River Basin, Washington, July 26–29, 1988—Continued

[Difference, calculated subtracted from measured; **bold site name**, main stem site; →, tributary inflowing site; ←, canal outflowing site; --, not applicable; nd, no data; canal loads are calculated using total nitrogen concentrations in the Yakima River near the point of diversion; N, streamflow entitlement for a diversion canal; E, estimate; No., number; loads in parentheses are not included in the calculations of main stem load]

Site name	Yakima River mile	Streamflow (cubic feet per second [ft^3/s]): Main stem: Measured	Streamflow: Main stem: Calculated	Streamflow: Main stem: Difference	Streamflow: Tributary inflowing	Streamflow: Canal outflowing	Total nitrogen load (pounds per day): Main stem: Measured	Total nitrogen load: Main stem: Calculated	Total nitrogen load: Main stem: Difference	Total nitrogen load: Tributary inflowing	Total nitrogen load: Canal outflowing
Mid Valley—Continued											
→Yakima sewage treatment plant	111.0	--	--	--	26	--	--	--	--	1,600	--
→Wide Hollow Creek near Mouth at Union Gap	107.4	--	--	--	26	--	--	--	--	220	--
→Moxee sewage treatment plant	107.3	--	--	--	(.1)	--	--	--	--	(11)	--
→Moxee Drain at Thorp Road near Union Gap[7]	107.3	--	--	--	79	--	--	--	--	700	--
Lower Valley											
Yakima River above Ahtanum Creek at Union Gap	107.3	2,940	2,970	-30	--	--	5,700	14,790	-9,090	--	--
→Ahtanum Creek at Union Gap	106.9	--	--	--	7.1	--	--	--	--	33	--
←Wapato Canal	106.7	--	--	--	--	[8]1,700 E	--	--	--	--	3,300 E
←Sunnyside Canal	103.8	--	--	--	--	[8]1,150 E	--	--	--	--	2,200 E
Yakima River at river mile 91 at Zillah	91.2	[9]163	97.1	+65.9	--	--	440	233	+207	--	--
→Zillah sewage treatment plant	89.2	--	--	--	.3	--	--	--	--	12	--
→East Toppenish Drain at Wilson Road near Toppenish	86.0	--	--	--	30	--	--	--	--	730	--
→Sub-Drain No. 35 at Parton Road near Granger	83.2	--	--	--	34	--	--	--	--	480	--
→Granger sewage treatment plant	82.8	--	--	--	(.3)	--	--	--	--	(7)	--
→Granger Drain at mouth near Granger	82.8	--	--	--	49	--	--	--	--	1,000	--
Yakima River at Highway 223 Bridge above Marion Drain at Granger	82.7	282	276	+6	--	--	2,100	2,662	-562	--	--
→Marion Drain at Indian Church Road at Granger	82.6	--	--	--	39	--	--	--	--	610	--
→Toppenish Creek at Indian Church Road near Granger	80.4	--	--	--	54	--	--	--	--	840	--
Yakima River below Toppenish Creek at river mile 78.1	78.1	428	375	+53	--	--	4,200	3,550	+650	--	--
→Coulee Drain	77.0	--	--	--	28	--	--	--	--	[6]320	--
Yakima River at river mile 72 above Satus Creek near Sunnyside	72.4	513	456	+57	--	--	4,100	4,520	-420	--	--
→Satus Creek at gage at Satus	69.6	--	--	--	84	--	--	--	--	1,200	--
→South Drain	69.3	--	--	--	[10]82	--	--	--	--	[6]1,600	--
→Drainage Improvement District (DID) No. 7	65.1	--	--	--	[5]25 E	--	--	--	--	[11]500 E	--
→Sunnyside sewage treatment plant	61.0	--	--	--	(3.1)	--	--	--	--	(120)	--
→Sulphur Creek Wasteway near Sunnyside	61.0	--	--	--	151	--	--	--	--	2,900	--
→Mabton sewage treatment plant	60.5	--	--	--	.9	--	--	--	--	15	--
→Satus Drain 303	60.2	--	--	--	[5]60 E	--	--	--	--	[2]740 E	--
Yakima River at Euclid Bridge at river mile 55 near Grandview	55.0	972	916	+56	--	--	[12]10,000	11,055	-1,055	--	--
←Chandler Canal at Bunn Road at Prosser	47.1	--	--	--	--	[13]808	--	--	--	--	8,300
→Prosser sewage treatment plant	46.5	--	--	--	1.7	--	--	--	--	38	--

Table 13. Estimated mass balances for instantaneous streamflows and total nitrogen loads in the main stem, selected major tributaries, and canals, Yakima River Basin, Washington, July 26–29, 1988—Continued

[Difference, calculated subtracted from measured; **bold site name**, main stem site; ➜, tributary inflowing site; ←, canal outflowing site; --, not applicable; nd, no data; canal loads are calculated using total nitrogen concentrations in the Yakima River near the point of diversion; N, streamflow entitlement for a diversion canal; E, estimate; No., number; loads in parentheses are not included in the calculations of main stem load]

Site name	Yakima River mile	Streamflow (cubic feet per second [ft³/s])					Total nitrogen load (pounds per day)				
		Main stem					Main stem				
		Measured	Calculated	Difference	Tributary inflowing	Canal outflowing	Measured	Calculated	Difference	Tributary inflowing	Canal outflowing
Lower Valley—Continued											
Yakima River above Snipes Creek and Spring Creek near Whitstran	43.0	206	166	+40	--	--	1,900	1,738	+162	--	--
➜Spring Creek at mouth at Whitstran	41.8	--	--	--	24	--	--	--	--	170	--
➜Snipes Creek at mouth at Whitstran	41.8	--	--	--	33	--	--	--	--	100	--
➜Chandler Power Return	35.8	--	--	--	[4]527	--	--	--	--	5,400 E	--
←Kiona Canal	34.9	--	--	--	--	[4]23 N	--	--	--	--	220
➜Corral Canyon Creek at mouth near Benton	33.5	--	--	--	16	--	--	--	--	[2]200	--
Yakima River at Kiona	29.9	854	783	+71	--	--	6,900	7,550	-650	--	--
←Columbia Canal	18	--	--	--	--	[4]100 E	--	--	--	--	810 E
←Richland Canal	18	--	--	--	--	[4]45 E	--	--	--	--	360 E
Yakima River at Van Geisan Bridge near Richland	8.4	706	709	-3	--	--	nd	5,730	--	--	--

[1]Load is based on concentrations measured July 12, 1988.
[2]Load is based on concentrations measured during the July 1987 synoptic survey.
[3]Load is based on concentrations measured September 18, 1990.
[4]Don Schramm, Bureau of Reclamation, oral commun., June 28, 1994.
[5]Bureau of Reclamation and Soil and Conservation Service, 1974.
[6]Load is based on concentrations measured during the August 1986 preliminary synoptic survey.
[7]The values reported for this site are the means of four daily measurements made from July 26-29, 1988.
[8]Daily mean streamflow for the period July 26–29, 1988 (Don Schramm, Bureau of Reclamation, oral commun., June 29, 1994).
[9]Streamflow in the Yakima River below the Parker diversion into Sunnyside Canal (river mile 103.7) ranged from 75 to 607 ft^3/s for the period July 26–29, 1988 (Don Schramm, Bureau of Reclamation, oral commun., June 29, 1994).
[10]Streamflow was measured June 27, 1989.
[11]Load is based on the calculated total nitrogen concentration from South Drain (river mile 69.3).
[12]Load is based on the average (1.9 milligrams per liter [mg/L]) of concentrations measured on July 28, 1988 at 0915 (2.3 mg/L) and 1010 (1.5 mg/L).
[13]281 ft^3/s were diverted into the Kennewick Canal at the Chandler power return at river mile 35.8 (Don Schramm, Bureau of Reclamation, oral commun., June 28, 1994).

Table 14. Estimated mass balances for instantaneous streamflows and total phosphorus loads in the main stem, selected major tributaries, and canals, Yakima River Basin, Washington, July 26–29, 1988

[Difference, calculated subtracted from measured; **bold site name**, main stem site; →, tributary inflowing site; ←, canal outflowing site; --, not applicable; nd, no data; canal loads are calculated using total phosphorus concentrations in the Yakima River near the point of diversion; N, streamflow entitlement for a diversion canal; E, estimate; No., number; loads in parentheses are not included in the calculations of main stem load]

Site name	Yakima River mile	Streamflow (cubic feet per second [ft^3/s])					Total phosphorus load (pounds per day)				
		Main stem					Main stem				
		Measured	Calculated	Difference	Tributary inflowing	Canal outflowing	Measured	Calculated	Difference	Tributary inflowing	Canal outflowing
					Kittitas Valley						
Yakima River below Keechelus Dam	214.4	841	--	--	--	--	nd	nd	nd	--	--
→Kachess River	203.5	--	--	--	872	--	--	--	--	nd	--
←Kittitas Main Canal at Diversion at Easton	202.5	--	--	--	--	1,120	--	--	--	--	nd
→Cle Elum River below Cle Elum Lake	185.6	--	--	--	3,050	--	--	--	--	nd	--
Yakima River at Cle Elum	183.1	3,780	3,640	+140	--	--	[1]200	nd	--	--	--
→Cle Elum sewage treatment plant	180.6	--	--	--	1.0	--	--	--	--	12	--
→Teanaway River Below Forks near Cle Elum	176.1	--	--	--	37	--	--	--	--	[2]2	--
→Taneum Creek	166.1	--	--	--	8	--	--	--	--	[3].4	--
←West Side Ditch	166.1	--	--	--	--	[4]105 N	--	--	--	--	6
Yakima River at Thorp Highway Bridge at Ellensburg	165.4	3,590	3,720	-130	--	--	970	208	+762	--	--
←Town Canal	161.3	--	--	--	--	[4]110 N	--	--	--	--	30
←Cascade Canal	160.3	--	--	--	--	[4]150 N	--	--	--	--	40
←Miscellaneous small diversions (each less than 30 ft^3/s)	160–155.5	--	--	--	--	[5]175	--	--	--	--	58 E
→Miscellaneous small irrigation returns (each less than 30 ft^3/s)	160–155.5	--	--	--	[5]170	--	--	--	--	190 E	--
→Manastash Creek	154.5	--	--	--	35 E	--	--	--	--	[6]13 E	--
→Ellensburg sewage treatment plant	151.5	--	--	--	6.5	--	--	--	--	42	--
→Wilson Creek above Cherry Creek at Thrall	147.0	--	--	--	83	--	--	--	--	72	--
→Cherry Creek at Thrall	147.0	--	--	--	127	--	--	--	--	170	--
					Mid Valley						
Yakima River at Umtanum	140.4	3,800	3,580	+220	--	--	820	1,329	-509	--	--
→Umtanum Creek	139.8	--	--	--	5 E	--	--	--	--	[3]2 E	--
←Roza Canal	127.9	--	--	--	--	[4]1,920 E	--	--	--	--	410 E
←Selah/Moxee Canal	123.6	--	--	--	--	[4]80 N	--	--	--	--	17
Yakima River at Harrison Road Bridge near Pomona	121.7	1,800	1,800	+0	--	--	1,400	395	+1,005	--	--

Table 14. Estimated mass balances for instantaneous streamflows and total phosphorus loads in the main stem, selected major tributaries, and canals, Yakima River Basin, Washington, July 26–29, 1988—Continued

[Difference, calculated subtracted from measured; **bold site name**, main stem site; →, tributary inflowing site; ←, canal outflowing site; --, not applicable; nd, no data; canal loads are calculated using total phosphorus concentrations in the Yakima River near the point of diversion; N, streamflow entitlement for a diversion canal; E, estimate; No., number; loads in parentheses are not included in the calculations of main stem load]

Site name	Yakima River mile	Streamflow (cubic feet per second [ft^3/s])					Total phosphorus load (pounds per day)				
		Main stem					Main stem				
		Measured	Calculated	Difference	Tributary inflowing	Canal outflowing	Measured	Calculated	Difference	Tributary inflowing	Canal outflowing
Mid Valley—Continued											
→Selah sewage treatment plant	117.0	--	--	--	1.6	--	--	--	--	55	--
→Naches River near North Yakima	116.3	--	--	--	328	--	--	--	--	440	--
← Moxee Canal	115.9	--	--	--	--	[5]45 E	--	--	--	--	39 E
→Roza Power Plant Return Flow	113.3	--	--	--	[4]755 E	--	--	--	--	160 E	--
→Yakima sewage treatment plant	111.0	--	--	--	26	--	--	--	--	510	--
→Wide Hollow Creek near Mouth at Union Gap	107.4	--	--	--	26	--	--	--	--	18	--
→Moxee sewage treatment plant	107.3	--	--	--	(.1)	--	--	--	--	(3)	--
→Moxee Drain at Thorp Road near Union Gap[7]	107.3	--	--	--	79	--	--	--	--	120	--
Lower Valley											
Yakima River above Ahtanum Creek at Union Gap	107.3	2,940	2,970	-30	--	--	1,400	2,664	-1,264	--	--
→Ahtanum Creek at Union Gap	106.9	--	--	--	7.1	--	--	--	--	5	--
← Wapato Canal	106.7	--	--	--	--	[8]1,700 E	--	--	--	--	820 E
← Sunnyside Canal	103.8	--	--	--	--	[8]1,150 E	--	--	--	--	560 E
Yakima River at river mile 91 at Zillah	91.2	[9]163	97.1	+65.9	--	--	44	25	-19	--	--
→Zillah sewage treatment plant	89.2	--	--	--	.3	--	--	--	--	14	--
→East Toppenish Drain at Wilson Road near Toppenish	86.0	--	--	--	30	--	--	--	--	51	--
→Sub-Drain No. 35 at Parton Road near Granger	83.2	--	--	--	34	--	--	--	--	16	--
→Granger sewage treatment plant	82.8	--	--	--	(.3)	--	--	--	--	(6)	--
→Granger Drain at mouth near Granger	82.8	--	--	--	49	--	--	--	--	190	--
Yakima River at Highway 223 Bridge above Marion Drain at Granger	82.7	282	276	+6	--	--	210	315	-102	--	--
→Marion Drain at Indian Church Road at Granger	82.6	--	--	--	39	--	--	--	--	17	--
→Toppenish Creek at Indian Church Road near Granger	80.4	--	--	--	54	--	--	--	--	32	--
Yakima River below Toppenish Creek at river mile 78.1	78.1	428	375	+53	--	--	370	259	+111	--	--
→Coulee Drain	77.0	--	--	--	28	--	--	--	--	[6]9	--
Yakima River at river mile 72 above Satus Creek near Sunnyside	72.4	513	456	+57	--	--	280	379	-99	--	--
→Satus Creek at gage at Satus	69.6	--	--	--	84	--	--	--	--	59	--
→South Drain	69.3	--	--	--	[10]82	--	--	--	--	[6]57	--
→Drainage Improvement District (DID) No. 7	65.1	--	--	--	[5]25 E	--	--	--	--	[11]18 E	--

Table 14. Estimated mass balances for instantaneous streamflows and total phosphorus loads in the main stem, selected major tributaries, and canals, Yakima River Basin, Washington, July 26–29, 1988—Continued

[Difference, calculated subtracted from measured; **bold site name**, main stem site; ➜, tributary inflowing site; ←, canal outflowing site; --, not applicable; nd, no data; canal loads are calculated using total phosphorus concentrations in the Yakima River near the point of diversion; N, streamflow entitlement for a diversion canal; E, estimate; No., number; loads in parentheses are not included in the calculations of main stem load]

Site name	Yakima River mile	Streamflow (cubic feet per second [ft^3/s]) Main stem: Measured	Streamflow Main stem: Calculated	Streamflow Main stem: Difference	Streamflow: Tributary inflowing	Streamflow: Canal outflowing	Total phosphorus load (pounds per day) Main stem: Measured	Total phosphorus load Main stem: Calculated	Total phosphorus load Main stem: Difference	Total phosphorus load: Tributary inflowing	Total phosphorus load: Canal outflowing
Lower Valley—Continued											
➜Sunnyside sewage treatment plant	61.0	--	--	--	(3.1)	--	--	--	--	(35)	--
➜Sulphur Creek Wasteway near Sunnyside	61.0	--	--	--	151	--	--	--	--	200	--
➜Mabton sewage treatment plant	60.5	--	--	--	.9	--	--	--	--	40	--
➜Satus Drain 303	60.2	--	--	--	[5]60 E	--	--	--	--	[2]58 E	--
Yakima River at Euclid Bridge at river mile 55 near Grandview	55.0	972	916	+56	--	--	680	712	-32	--	--
← Chandler Canal at Bunn Road at Prosser	47.1	--	--	--	--	[12]808	--	--	--	--	570
➜Prosser sewage treatment plant	46.5	--	--	--	1.7	--	--	--	--	160	--
Yakima River above Snipes Creek and Spring Creek near Whitstran	43.0	206	166	+40	--	--	240	270	-30	--	--
➜Spring Creek at mouth at Whitstran	41.8	--	--	--	24	--	--	--	--	17	--
➜Snipes Creek at mouth at Whitstran	41.8	--	--	--	33	--	--	--	--	16	--
➜Chandler Power Return	35.8	--	--	--	[4]527	--	--	--	--	370 E	--
← Kiona Canal	34.9	--	--	--	--	[4]23 N	--	--	--	--	19
➜Corral Canyon Creek at mouth near Benton	33.5	--	--	--	16	--	--	--	--	[2]7	--
Yakima River at Kiona	29.9	854	783	+71	--	--	640	631	+9	--	--
← Columbia Canal	18	--	--	--	--	[4]100 E	--	--	--	--	75 E
← Richland Canal	18	--	--	--	--	[4]45 E	--	--	--	--	34 E
Yakima River at Van Geisan Bridge near Richland	8.4	706	709	-3	--	--	nd	531	--	--	--

[1]Load is based on concentrations measured July 12, 1988.
[2]Load is based on concentrations measured during the July 1987 synoptic survey.
[3]Load is based on concentrations measured September 18, 1990.
[4]Don Schramm, Bureau of Reclamation, oral commun., June 28, 1994.
[5]Bureau of Reclamation and Soil Conservation Service, 1974.
[6]Load is based on concentrations measured during the August 1986 preliminary synoptic survey.
[7]The values reported for this site are the means of four daily measurements made from July 26–29, 1988.
[8]Daily mean streamflow for the period July 26–29, 1988 (Don Schramm, Bureau of Reclamation, oral commun., June 29, 1994).
[9]Streamflow in the Yakima River below the Parker diversion into Sunnyside Canal (river mile 103.7) ranged from 75 to 607 ft^3/s for the period July 26–29, 1988 (Don Schramm, Bureau of Reclamation, oral commun., June 29, 1994).
[10]Streamflow was measured June 27, 1989.
[11]Load is based on the calculated total phosphorus concentration from South Drain (river mile 69.3).
[12]281 ft^3/s were diverted into the Kennewick Canal at the Chandler power return at river mile 35.8 (Don Schramm, Bureau of Reclamation, oral commun., June 28, 1994).

loads on the lower main stem was minimized. The indirect effect of irrigation water diverted around Zillah and returned later through lower basin drains, however, may have been considerable.

In the lower main stem downstream from Zillah, agricultural drains were the primary source of flows and nutrient loads during the synoptic period. Total nitrogen and total phosphorus loads at Zillah were only 4.4 and 6.5 percent, respectively, of the loads measured at Grandview (RM 55). In fact, 67 percent of the total nitrogen and 74 percent of the total phosphorus loads in the main stem at Grandview were derived from four agricultural drains: Granger Drain (RM 82.8), Satus Creek (RM 69.6), South Drain (RM 69.3), and Sulphur Creek Wasteway (RM 61.0) (tables 13 and 14). The total nitrogen load decreased between Grandview and Kiona (RM 29.9), with most of the decrease resulting from the net diversion of 2,900 lb/day into Chandler Canal (8,300 lb/day diverted into Chandler Canal [RM 47.1] and 5,400 lb/day returned through the Chandler Power Return [RM 35.8]) and subsequently into Kennewick Canal. Similarly, total phosphorus loads were decreased by 200 lb/day between Grandview and Kiona; however, this decrease was less notable as a result of the 160 lb/day contribution from the Prosser sewage treatment plant (RM 46.5). Therefore, the result was a net decrease of 40 lb/day of total phosphorus in this reach (tables 13 and 14).

Implications for Water Resource Monitoring and Regulation

The median total nitrogen and total phosphorus concentrations were 8 and 19 times, respectively, larger at the agricultural sites than at the forested sites. The pattern of low concentrations from forest dominated sites and high concentrations from agriculturally dominated sites underscores the significance of agricultural activities on water quality in the Yakima River Basin.

The large downstream increase (factor of 10) in total nitrogen concentrations between Cle Elum and Kiona emphasizes the impact of agricultural fertilizers, beef and dairy practices, and sewage from municipal and septic tank sources on water quality in the Mid and Lower Valley. The presence of a large proportion of the total nitrogen as nitrite plus nitrate is significant because nitrite and nitrate are readily used by algae and rooted aquatic plants. Such aquatic growth was present downstream from RM 60 (near Sunnyside).

Total phosphorus concentrations also increased by a factor of 10 between Cle Elum and Kiona, with concentrations ranging from 0.1 to 0.2 mg/L between Grandview and Kiona. Sewage treatment plants and suspended sediment from the tributaries were considered to be primary sources. Sulphur Creek Wasteway provided a significant input of phosphorus to the main stem.

The similarity between irrigation and winter seasonal loads of nitrite plus nitrate and SRP at Union Gap and Naches River may be indicative of a somewhat constant source of nutrients, typical of reaches affected by ground-water seepage and point source discharges. Additionally, the doubling of the SRP load between Umtanum and Union Gap is indicative of a substantial source of SRP upstream from Union Gap. The fairly even distribution of nitrite plus nitrate loads among the seasons at Sulphur Creek implies that nitrogen based fertilizers were infiltrating shallow ground water and subsequently discharging to Sulphur Creek. Other possible nitrogen sources included animal waste runoff from feedlots and the land-based application of solid and liquid forms of manure.

The large streamflows associated with the snowmelt season were important in the transport of suspended sediment and associated nutrients from the Yakima River Basin to the Columbia River. As a result, streamflow management activities that increase the storage of snowmelt runoff may reduce the flushing or transport of sediment sorbed nutrients out of the upper basin and consequently decrease the supply of nutrients to nuisance aquatic plants in the lower basin.

Pesticides and Other Organic Compounds

By Joseph F. Rinella

Hundreds of different man-made organic compounds are used annually in industry, forestry, and agriculture in the Yakima River Basin. Some of these compounds are hydrophobic and sorb onto soil particles and stream sediment, whereas other compounds are hydrophilic and readily dissolve in water. Several of these compounds are lipophilic and tend to accumulate in fatty tissues of aquatic biota. Sources of organic compounds from agricultural return flow, stormwater runoff, ground-water seepage, and municipal and industrial effluent can result in the direct transport of these compounds into surface water. The ease of transport of these potentially toxic compounds into streams makes knowledge of their occurrence and behavior essential for water management in the basin.

This section of the report summarizes an interpretive report (Rinella and others, 1999) on the occurrence, distribution, transport, fate, and potential effects of pesticides and other organic compounds in streams in the Yakima River Basin. Organic compound data were collected from about 100 sampling sites during the 1987–91 WY (Rinella, McKenzie, Crawford, and others, 1992). Because of intense irrigation and pesticide use in the agricultural areas, one focus of this study was on agricultural pesticides. The study was designed to provide information on major natural and human factors that affect (1) the spatial distribution of organic compound concentrations in water, suspended sediment, bed sediment, and aquatic biota, (2) the seasonal variations of organic compound concentrations and loads in streams, (3) the suitability of surface water for the protection of aquatic biota and human health, on the basis of Federal and State water-quality guidelines, criteria, and regulations, and (4) the patterns of organic compound concentrations that are common among water, sediment, and aquatic biota. In this study, water, suspended sediment, streambed sediment, aquatic biota (fish, crayfish, mollusks, and plants), and agricultural soils were collected and analyzed for a variety of pesticides and other organic compounds that have been or continue to be used in the basin.

Estimates of pesticide use indicate that about 3 million kilograms (3,300 tons) of active ingredients were applied in the basin in 1989 to increase the production and quality of agricultural crops. Although pesticide use in the basin has been and continues to be extensive, historically, relatively few water-quality samples have been collected to determine the spatial distribution and temporal variation of pesticide concentrations in the aquatic environment. The small amount of data available prior to 1987 showed that concentrations of many pesticides in water were less than the conventional minimum reporting levels. These minimum reporting levels, however, were too high for water managers to adequately assess stream quality conditions because the reporting levels sometimes exceeded levels of environmental concern. Consequently, research procedures were developed in this study to reduce minimum reporting levels by a factor of 10 or more by analyzing large sample volumes—up to 120 liters (L) for filtered water and 224 L for the suspended phase (Rinella, McKenzie, Crawford, and others, 1992).

In 1989, about 180 pesticides were applied in the Yakima River Basin. Fifty-four of these compounds were analyzed in this study, and 43 of the 54 compounds analyzed (80 percent) were detected at trace or quantifiable concentrations in soil, bed sediment, suspended sediment, water, and (or) aquatic biota at one or more sampling sites. Including other organic compounds associated with industrial and urban activities, as well as persistent pesticides that were used historically, more than 110 organic compounds were detected in Yakima River Basin streams during the 1987–91 WY.

Temporal Variation

Early in the study, seasonal fixed-site data were collected to determine the temporal variation of pesticide concentrations in the streams. These data were used to design and conduct a synoptic study to determine the spatial distribution, sources, and transport of pesticides during a period when compound concentrations and loads were expected to be high. The seasonal data were collected from eight sites (one pristine forested site, five agricultural return flows, one urban site, and one main stem site) in May, June, July, August, and November 1988, and March 1989.

In 1988, concentrations of soluble and relatively insoluble pesticides generally began to increase in agricultural runoff in June in response to increased irrigation runoff following springtime pesticide applications (table 15). This pattern of occurrence in the Yakima River Basin is similar to the runoff pattern of herbicides in the Mississippi River and other streams in the Midwestern United States, where the highest concentrations occurred in response to flushing by late spring and early summer rainfall immediately following pesticide applications (Thurman and others, 1991). Unlike the Midwestern streams, however, rainfall in the Yakima River Basin was low during the spring and summer periods following pesticide applications. As a result, irrigation at or near peak water use flushed relatively high pesticide loads and concentrations to streams in June and July. In addition, high pesticide loads and concentrations were flushed to the streams in the Yakima River Basin by storm runoff from agricultural fields, as observed in March 1989 (table 15).

The highest concentrations of suspended sediment also occurred in June and July 1988 and during storm runoff in March 1989 (table 15), thereby suggesting that eroding soil was associated with the transport of sorbed pesticides from fields to streams during periods of overland flow. Theoretical equilibrium-partitioning calculations indicate that hydrophilic and hydrophobic compounds with sediment-water partition coefficients (K_{oc}) larger than about 85 mL/g (milliliters per gram) are sorbed mostly to soils prior to soil erosion (fig. 22; for perspective, [2,4-dichlorophenoxy] acetic acid [2,4-D] is a hydrophilic compound with a K_{oc} of 20 mL/g, and 4,4’-dichlorodiphenyltrichlorethane [DDT] is a hydrophobic compound with a K_{oc} of about 240,000 mL/g). For example, diazinon is highly soluble in water and has a K_{oc} of 85 mL/g. For soils in the Yakima River Basin containing 1 percent organic carbon, about 64 percent of the diazinon in the fields is theoretically sorbed to soil particles and 36 percent is associated with soil-pore water. As the soils and soil-pore water are flushed and (or) eroded by irrigation water in overland flow, both the sorbed and soluble phases of diazinon are transported to the streams. Once the soil is suspended in surface water and the mass of soil decreases from the high concentrations in the fields (about 2,000,000 milligrams of dry soil per liter of moist soil) to lower concentrations in agricultural return flows (typically 500 mg/L or less), equilibrium partitioning favors desorption of hydrophilic compounds into the dissolved phase. For example, more than 99 percent of the total diazinon mass will equilibrate into the dissolved phase in the agricultural returns (table 16).

In the Yakima River Basin, pesticide concentrations decreased by the end of the irrigation season because of decreases in pesticide application, erosion, and overland runoff (table 15). Pesticides that were applied early in the growing season also had increased time to undergo chemical and biological degradation and volatilization throughout the summer months. Compounds persistent in soils, however, continued to be transported throughout the year, especially during storm runoff from agricultural areas. Annual precipitation in the agricultural areas was typically small (less than 10 inches).

Spatial Distribution

Stream Water

Pesticide concentrations in the Yakima River Basin are controlled primarily by dilution from streamflow from the upper basin and pesticide contributions from agricultural areas. During the irrigation season, streamflow throughout the basin is regulated extensively by storage reservoirs and irrigation diversions. Upstream from the Roza Canal diversion (RM 127.9), streamflow in the Yakima River is augmented by releases from three large storage reservoirs, which result in main stem flows that typically range from 3,000 to 4,000 ft^3/s (fig. 23). In this upper reach, agricultural returns from the Kittitas Valley convey pesticides to the Yakima River, where flow augmentation substantially dilutes the pesticide concentrations in the main stem. Downstream from the Wapato and Sunnyside Canal diversions (RMs 106.7 and 103.8, respectively), streamflow in the Yakima River is reduced to only a few hundred cubic feet per second. Many of the agricultural return flows drain into the lower Yakima River and typically account

Table 15.Concentrations of selected pesticides and suspended sediment in unfiltered water samples, Yakima River Basin, Washington, 1988–89

[A range of values is shown when multiple determinations were made in a month, otherwise the values are for one sample; DDT+DDE+DDD, 4,4'-dichlorodiphenyl-trichloroethane plus 4,4'-dichlorodiphenyldichloroethylene plus 4,4'-dichlorodiphenyldichloroethane; <, less than; --, no data available; *, highest concentration at site; **, second highest concentration at site; data in this table are adapted from Rinella, McKenzie, Crawford, and others (1992)]

Site name	Concentration (nanograms per liter)						
	May 1988	June 1988	July 1988	August/ September 1988	November 1988	March 1989	December 1989
DDT + DDE + DDD							
Cle Elum River above Cle Elum Lake	<3	<3	<3	<3	<3	<3	--
Cherry Creek at Thrall	2	1	4**	4**	2	39*	--
Moxee Drain at Thorp Road	8–9	21–42**	31–76*	14	3	5	--
Wide Hollow Creek near mouth	4	10**	4	2	1	91*	--
Granger Drain at mouth	41	40–110**	96–122*	36	19	28	--
Toppenish Creek at Indian Church Road	1	1	2**	1	5*	<3	--
Sulphur Creek Wasteway near Sunnyside	12	27–51*	35**	13–14	10	6	--
Yakima River at Kiona	5**	<3–3	1	2	1	14*	1
Dieldrin							
Cle Elum River above Cle Elum Lake	<1	<1	<1	<1	<1	<1	--
Cherry Creek at Thrall	3	3	12**	5	1	41*	--
Moxee Drain at Thorp Road	1	<1–4**	6–8*	2	<1	<1	--
Wide Hollow Creek near mouth	2**	2**	3*	<1	2**	<1	--
Granger Drain at mouth	6	<1–9**	17–30*	8	5	<1	--
Toppenish Creek at Indian Church Road	1	7*	3**	1	<1	<1	--
Sulphur Creek Wasteway near Sunnyside	2	<1–5	14–15*	6**	4	3	--
Yakima River at Kiona	1	<1–2**	3*	2**	<1	<1	<1
Diazinon							
Cle Elum River above Cle Elum Lake	<10	<10	<10	<10	<10	<10	--
Cherry Creek at Thrall	<10	<10	<10	<10	<10	<10	--
Moxee Drain at Thorp Road	<10	10–370**	130–630*	30	<10	<10	--
Wide Hollow Creek near mouth	<10	120*	10**	<10	<10	<10	--
Granger Drain at mouth	<10	<10–10	10–30*	10**	<10	<10	--
Toppenish Creek at Indian Church Road	<10	<10	150*	10**	<10	<10	--
Sulphur Creek Wasteway near Sunnyside	<10	<10–20**	10–20*	<10–10	<10	<10	--
Yakima River at Kiona	<10	<10–30**	250*	10	<10	<10	<10
Parathion							
Cle Elum River above Cle Elum Lake	<10	<10	<10	<10	<10	<10	--
Cherry Creek at Thrall	<10	<10	<10	<10	<10	<10	--
Moxee Drain at Thorp Road	<10	<10	10–100*	<10	<10	<10	--
Wide Hollow Creek near mouth	<10	10*	<10	<10	<10	<10	--
Granger Drain at mouth	<10	<10	<10	<10	<10	<10	--
Toppenish Creek at Indian Church Road	<10	<10	20*	<10	<10	<10	--
Sulphur Creek Wasteway near Sunnyside	<10	<10–10*	<10	<10	<10	<10	--
Yakima River at Kiona	<10	<10–10**	60*	<10	<10	<10	<10

Table 15.Concentrations of selected pesticides and suspended sediment in unfiltered water samples, Yakima River Basin, Washington, 1988–89—Continued

[A range of values is shown when multiple determinations were made in a month, otherwise the values are for one sample; DDT+DDE+DDD, 4,4'-dichlorodiphenyltrichloroethane plus 4,4'-dichlorodiphenyldichloroethylene plus 4,4'-dichlorodiphenyldichloroethane; <, less than; --, no data available; *, highest concentration at site; **, second highest concentration at site; data in this table are adapted from Rinella, McKenzie, Crawford, and others (1992)]

Site name	Concentration (nanograms per liter)						
	May 1988	June 1988	July 1988	August/ September 1988	November 1988	March 1989	December 1989
(2,4-dichlorophenoxy) acetic acid [2,4-D]							
Cle Elum River above Cle Elum Lake	<10	<10	<10	<10	220*	<10	--
Cherry Creek at Thrall	7,500*	140–150	480**	60	<10	200	--
Moxee Drain at Thorp Road	20–120	<10–150	200–1,900*	50	<10	270**	--
Wide Hollow Creek near mouth	<10	250*	20**	<10	<10	<10	--
Granger Drain at mouth	<10	<10–430*	330–410**	<10	<10	<10	--
Toppenish Creek at Indian Church Road	<10	160*	30	40**	40**	<10	--
Sulphur Creek Wasteway near Sunnyside	10	<10–100*	<10–90**	50–60	100*	<10	--
Yakima River at Kiona	10	70–110*	70**	40	<10	<10	--
Atrazine							
Cle Elum River above Cle Elum Lake	<100	<100	<100	<100	<100	<100	--
Cherry Creek at Thrall	70	20–60	78**	61	48	600*	--
Moxee Drain at Thorp Road	30*	10	<100–17	16**	<100	<100	--
Wide Hollow Creek near mouth	<100	40*	<100	<100	<100	11**	--
Granger Drain at mouth	90	90	40–47	120**	<100	280*	--
Toppenish Creek at Indian Church Road	50	60*	54**	43	23	<100	--
Sulphur Creek Wasteway near Sunnyside	60*	20–22	25–31	34	<100	44**	--
Yakima River at Kiona	50*	<100–30	49**	30	<100	<100	--
Simazine							
Cle Elum River above Cle Elum Lake	<100	<100	<100	<100	<100	<100	--
Cherry Creek at Thrall	90	<100–40	220**	23	<100	6,600*	--
Moxee Drain at Thorp Road	20**	<100–10	<100–24*	<100	<100	18	--
Wide Hollow Creek near mouth	26	40	33**	22	<100	43*	--
Granger Drain at mouth	80	170–460*	91–100**	24	<100	100**	--
Toppenish Creek at Indian Church Road	<100	40**	45*	16	<100	11	--
Sulphur Creek Wasteway near Sunnyside	120*	60–77**	68–74	24–29	<100	34	--
Yakima River at Kiona	40	20–44**	49*	17	<100	28	--

Table 15.Concentrations of selected pesticides and suspended sediment in unfiltered water samples, Yakima River Basin, Washington, 1988–89—Continued

[A range of values is shown when multiple determinations were made in a month, otherwise the values are for one sample; DDT+DDE+DDD, 4,4'-dichlorodiphenyl-trichloroethane plus 4,4'-dichlorodiphenyldichloroethylene plus 4,4'-dichlorodiphenyldichloroethane; <, less than; --, no data available; *, highest concentration at site; **, second highest concentration at site; data in this table are adapted from Rinella, McKenzie, Crawford, and others (1992)]

Site name	Concentration (nanograms per liter)						
	May 1988	June 1988	July 1988	August/ September 1988	November 1988	March 1989	December 1989
Dicamba							
Cle Elum River above Cle Elum Lake	<10	<10	<10	<10	<10	<10	--
Cherry Creek at Thrall	2,600*	140	520**	50	<10	240	--
Moxee Drain at Thorp Road	30*	10	10–20**	10	<10	<10	--
Wide Hollow Creek near mouth	<10	20*	<10	<10	<10	10**	--
Granger Drain at mouth	<10	70–130*	40**	<10	<10	20	--
Toppenish Creek at Indian Church Road	10	70*	10	10	<10	<10	--
Sulphur Creek Wasteway near Sunnyside	20*	10–20*	<10–20**	10	<10	<10	--
Yakima River at Kiona	10	10–20*	10	20*	<10	<10	--
Suspended sediment, in milligrams per liter							
Cle Elum River above Cle Elum Lake	<1	3*	<1	1	2*	1	--
Cherry Creek at Thrall	91	64–121**	82	45	25	1,020*	--
Moxee Drain at Thorp Road	134–143	296–436**	443–607*	157	58	47	--
Wide Hollow Creek near mouth	17	8–28**	8	5	5	211*	--
Granger Drain at mouth	205	526–643*	421–432**	282	62	92	--
Toppenish Creek at Indian Church Road	32**	32	13	11	337*	30	--
Sulphur Creek Wasteway near Sunnyside	70	204–245*	99–128**	67–83	19	108	--
Yakima River at Kiona	28	30–35	22	35**	10	103*	57–71

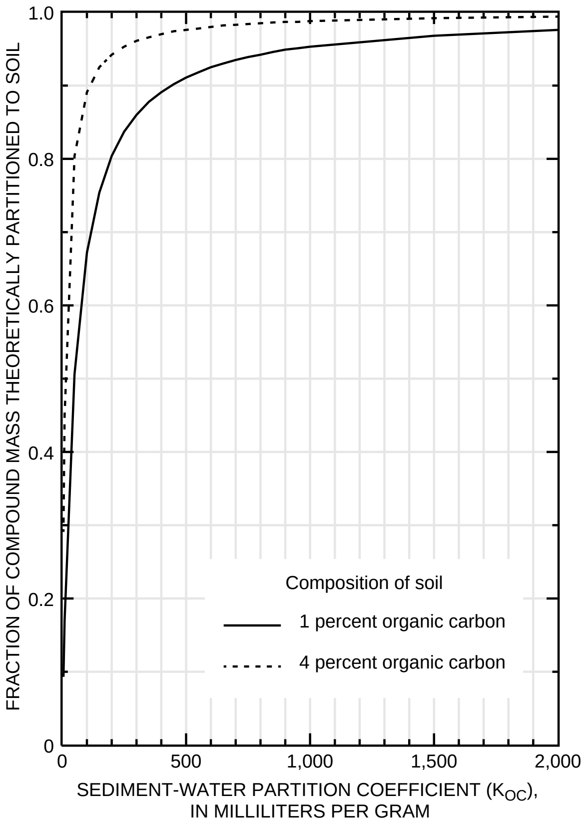


Figure 22.Theoretical relation, in a soil environment, between sediment-water partition coefficients and the fraction of organic compounds partitioned to the soil. (Equilibrium partitioning is assumed; the remaining compound fraction is dissolved in the soil-pore water.)

for as much as 80 percent of the main stem flow near the downstream terminus of the basin. As a result, concentrations of many pesticides increased substantially in the lower main stem as the proportion of agricultural return flow increased.

In June 1989, when pesticide concentrations were expected to be high because of irrigation runoff, water samples were collected from 29 sites in the Yakima River Basin to determine the spatial distribution of hydrophilic and hydrophobic pesticide concentrations and loads. The most frequently detected compounds in this synoptic sampling are listed in table 17. With the exception of chlordane, 4,4'-dichlorodiphenyltrichloroethane plus 4,4'-dichlorodiphenyldichloroethylene plus 4,4'-dichlorodiphenyldichloroethane (DDT+DDE+DDD), dieldrin, and prometon, these compounds were also among the most abundantly used compounds in the basin in 1989, which probably accounts for their frequent detections. Although the use or sale of DDT, dieldrin, and chlordane was banned or restricted in 1972, 1974, and 1987, respectively, these persistent compounds were detected frequently at trace or quantifiable concentrations (28 sites for DDT+DDE+DDD, 20 sites for dieldrin, and 11 sites for chlordane). The widespread occurrence of these pesticides suggests broad historical use throughout the basin. Estimated use of prometon in the basin was minimal; however, it has a relatively long half-life in soils (up to 500 days), which probably accounts for its high frequency of detections.

The predominant source area for many pesticides in the basin was the east side area (area east of the Yakima River from Moxee Valley downstream to Benton City near Kiona, including the Moxee, Granger, Sunnyside, and Whitstran areas) (table 18). This area had the largest acreage of irrigated land and generally received the largest application of pesticides. Owing, in part, to the highly erosive soils of the Warden-Esquatzel association (Rinella and others, 1999), steep subbasin slopes, and rill irrigation of tilled crops, the suspended sediment load in June 1989 to the Yakima River from the east side area was five or more times larger than loads from the other areas. Similarly, several of the more hydrophobic compound loads (DDT+DDE+DDD, dieldrin, endosulfan I, phorate, and propargite) were four or more times larger than loads from other areas. Concentrations of DDT+DDE+DDD, dieldrin, diazinon, malathion, phosphamidon, propargite, atrazine, and simazine significantly increased ($\rho \leq 0.02$) in Yakima River Basin streams as concentrations of suspended sediment increased. These correlations are consistent with the equilibrium-partitioning calculations, which indicate that hydrophobic and hydrophilic compounds with K_{oc} greater than 85 mL/g are being mobilized and transported, at least initially, in the suspended phase from the agricultural fields. Tributaries with the highest suspended sediment concentrations in June 1989 were agricultural return flows, which also had among the highest concentrations of many pesticides (table 17). As expected, sites upstream from agricultural activities (for example, Cooper River at Salmon LaSac, Umtanum Creek near mouth, and Satus Creek above Wilson-Charley Canyon) had among the lowest concentrations.

Table 16. Theoretical equilibrium partitioning of selected organic compounds sorbed to oil and dissolved in water, Yakima River Basin, Washington

[<, less than; >, greater than; 2,4-D, (2,4-dichlorophenoxy) acetic acid; DDT, 4,4'-dichlorodiphenyltrichloroethane; DDE, 4,4'-dichlorodiphenyldichloroethylene; DDD, 4,4'-dichlorodiphenyldichloroethane]

Compound	Sediment-water partition coefficient (K_{oc}), normalized to organic carbon, in milliliters per gram[1]	Partitioning of compounds in soils prior to erosion		Partitioning of compounds to soil suspended in water	
		Percent of compound mass sorbed to soils prior to erosion[2]	Percent of compound mass dissolved in soil-pore water[1]	Percent of compound mass sorbed to suspended soils[3]	Percent of compound mass dissolved in water[2]
Atrazine	163	77	23	< 1	> 99
2,4-D	20	29	71	< 1	> 99
DDT	243,000	> 99	< 1	55	45
DDE	4,400,000	> 99	< 1	96	4
DDD	770,000	> 99	< 1	79	21
Diazinon	85	64	36	< 1	> 99
Dicamba	2	4	96	< 1	> 99
Dieldrin	1,700	97	3	< 1	> 99
Parathion	10,700	> 99	< 1	5	95
Simazine	138	74	26	< 1	> 99

[1] Rinella and others, 1999.

[2] Calculation assumes sorption is controlled by partitioning to organic carbon, fraction organic carbon equals 1 percent, and soil moisture equals 10 percent.

[3] Calculation assumes sorption is controlled by partitioning to organic carbon, fraction organic carbon in soil equals 1 percent, and concentration of soil suspended in water is 500 milligrams per liter.

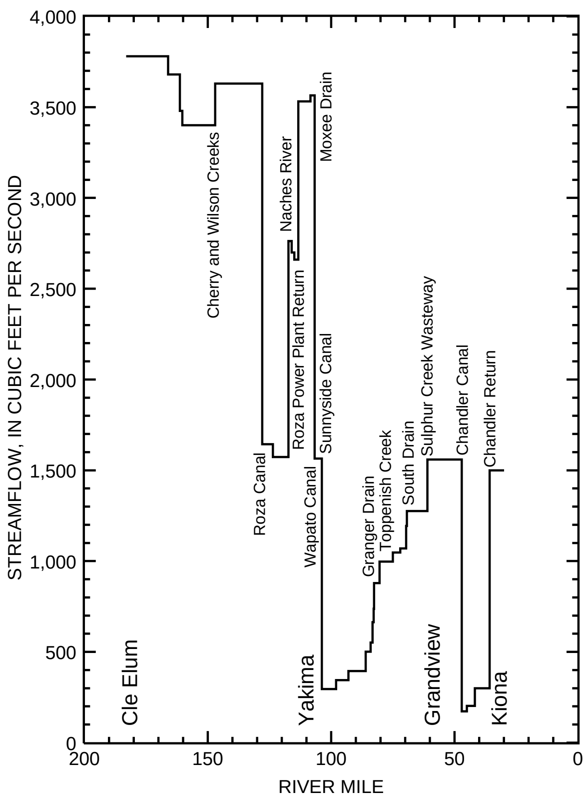


Figure 23. Instantaneous streamflow in the Yakima River as influenced by tributary contributions and canal diversions, Yakima River Basin, Washington, June 25–30, 1989.

Ratios of pesticide loads in runoff to the daily mean pesticide applications in 1989 in the Yakima River Basin generally were less than 0.6 percent. For these calculations, instantaneous pesticide loads measured near peak irrigation in June 1989 were computed in grams per day and divided by the 1989 pesticide applications, computed in grams per day (mass of annual application divided by 365 days). Ratios were computed for the most frequently quantified compounds (listed in table 17) except DDT+DDE+DDD, dieldrin, and chlordane, which were not applied in 1989. Instantaneous runoff loads near or during peak irrigation were expected to be larger than those instantaneous loads during nonirrigation season; consequently, the ratios computed in this study may be biased high when compared to ratios between annual loads in streams and annual applications. If, however, major storm runoff had occurred, the ratios may be biased low. These calculations indicate that less than 0.6 percent of the applied pesticide loads were detected in instantaneous loads in runoff. For comparison, ratios of annual herbicide loads in runoff to annual applications for Midwestern streams in the United States ranged from less than 0.1 to 3.7 percent and were similar to those in Yakima River Basin streams (Goolsby and Battaglin, 1993).

Organic compounds in the Yakima River Basin that exceeded chronic-toxicity water-quality criteria for the protection of freshwater aquatic life are listed in table 19. Most of the instantaneous concentrations that exceeded the chronic-toxicity criteria (usually based on sustained concentrations) occurred in agricultural returns and main stem sites downstream from the city of Yakima. Criteria for acute toxicity were not exceeded in the basin. Water-quality criteria by the U.S. Environmental Protection Agency (EPA) (1986) and (or) guidelines by the National Academy of Sciences and National Academy of Engineering (NAS-NAE) (1973) for the protection of freshwater aquatic life were not available for all of the pesticides that were applied in the basin in 1989. In addition, additive or synergistic effects that might result from the low level occurrence of several compounds in the water were not evaluated in this study.

In June 1989, the city of Yakima's finished drinking water supply was analyzed for 67 pesticides using research procedures to obtain minimum analytical reporting levels near 1 ηg/L (nanograms per liter). The only compound detected was DDE, at a concentration of 0.36 ηg/L. Assuming that a person ingests 2 L of this water each day, the increased lifetime (70 years) cancer risk was relatively small (4:1,000,000,000), using EPA's risk assessment methodology calculations. For this calculation, drinking water was assumed to be the sole source of DDE ingested by a person.

Bed Sediment and Agricultural Soil

Results from the sampling of 59 sites in the Yakima River Basin showed that several semivolatile and organochlorine compounds were detected in streambed sediment. The highest concentrations were detected in agricultural return flows, many of which also receive point source discharges and urban runoff. DDT+DDE+DDD and dieldrin are organochlorine insecticides that were detected in more than 50 percent of the samples. Phenol, bis(2-ethylhexyl)

Table 17. Streamflow, concentrations of suspended sediment, and most frequently detected pesticides in water samples from selected sites, Yakima River Basin, Washington, June 25–30, 1989

[DDT+DDE+DDD, 4,4'-dichlorodiphenyltrichloroethane (DDT) plus 4,4'-dichlorodiphenyldichloroethylene (DDE) plus 4,4'-dichlorodiphenyldichloroethane (DDD); EPTC, *S*-ethyl dipropylthiocarbamate; 2,4-D, (2,4-dichlorophenoxy) acetic acid; <, less than; T, present but below quantifiable concentration; >, greater than—the compound was quantified in one phase and detected but not quantified in the other phase; data in this table are adapted from Rinella, McKenzie, Crawford, and others (1992)]

	Concentrations (nanograms per liter)											
	Yakima River main stem sites (River mile)						Agricultural return flows near mouth (Yakima River mile confluence)					
Constituent	Cle Elum (183.1)	Umtanum (140.4)	Union Gap (107.3)	Near Sunnyside (72.0)	Near Grandview (55.0)	Kiona (29.9)	Cherry Creek (147.0)	Moxee Drain (107.3)	Granger Drain (82.8)	Satus Creek (69.6)	Sulphur Creek Wasteway (61.0)	Spring Creek (41.8)
Streamflow[1]	3,780	3,630	3,630	1,070	1,560	1,500	126	65	37	124	259	47
Suspended sediment[2]	6	25	24	44	47	30	120	440	640	38	240	200
Organochlorine compounds in unfiltered water (suspended plus dissolved phases[3])												
Chlordane, *cis*- and *trans*-	<.46	T <1.4	<1.4	<2.5	--	<1.4	>4.0	T <3.5	.14	<4.0	T <8.5	1.4
DDT+DDE+DDD	.50	.43	3.2	10	12	15	>8.0	36	83	2.5	57	50
Dieldrin	T <.23	.97	.77	1.1	>5.7	3.7	4.7	>.86	>3.6	1.7	37	7.9
Endosulfan I	T <.17	.82	.92	<.10	<.80	1.2	<.30	12	T <1.4	<.80	6.8	<.81
Organophosphorus compounds in unfiltered water (suspended plus dissolved phases[3])												
Chlorpyrifos	<.79	T <2.5	<2.3	T <3.2	T <2.3	>9.6	>.3	>.48	T <6.1	>.20	.16	3.0
Diazinon	.67	T <2.1	>7.9	35	>120	39	T <2.8	410	13	22	66	72
Dimethoate[4]	<1.2	<3.7	<3.5	<3.5	7.3	<3.7	<3.5	<13	T <12	7.7	330	<4.6
Malathion	1.5	T <4.0	25	14	8.6	70	T <2.8	T <11	T <10	14	T <44	48
Parathion	<1.0	T <3.3	T <3.2	11	30	T <3.3	<3.1	.14	<12	180	.10	12
Phorate	<.92	<2.9	3.6	T <3.5	T <3.0	T <2.9	5.5	130	<8.1	<4.9	T <40	<5.0
Phosphamidon[1]	T <2.1	T <6.5	T <6.1	T <2.4	22	5.3	<2.4	43	56	<4.5	T <37	6.7
Thiocarbamate and sulfite compounds in filtered water												
EPTC	<.35	1.6	1.1	7.3	3.8	3.3	37	T <2.7	3.1	2.9	T <5.0	3.3
Propargite	T <.68	T <2.1	3.0	17	44	7.2	T <4.6	210	40	14	260	3.0
Acetamide and triazine compounds in filtered water												
Alachlor	<.52	<1.6	<1.5	11	19	12	<1.2	<4.0	33	13	33	<2.0
Atrazine	.27	10	5.6	26	61	32	71	8.5	48	46	49	13
Metolachlor	<.42	T <1.3	T <1.2	.93	1.3	1.9	<.70	<3.1	T <2.8	4.1	T <15	<1.8
Prometon	<.27	1.1	1.4	2.4	5.2	3.0	1.4	3.8	32	<2.5	26	<2.5
Simazine	.25	2.2	3.9	16	33	18	11	<3.6	130	27	81	10
Chlorophenoxy-acetic acid and benzoic compounds in filtered water												
2,4-D	<10	<10	70	<10	70	90	290	120	140	<10	80	60
Dicamba	<10	10	<10	<10	<10	<10	100	<10	50	<10	10	10

[1]Streamflow is reported in cubic feet per second.

[2]Suspended sediment concentrations are reported in milligrams per liter.

[3]"Dissolved" refers to the filtrate that passes through a 1-micrometer pore-size filter.

[4]Dimethoate and phosphamidon were not analyzed for in suspended sediment.

Table 18. Instantaneous loads of suspended sediment and selected pesticides in water samples, Yakima River Basin, Washington, June 25–30, 1989

[East side, the area east of the Yakima River from Moxee Valley downstream to Benton City near Kiona including the Moxee, Granger, Sunnyside, and Whitstran areas; West side, the area west of the Yakima River downstream from Ahtanum Ridge to the City of Mabton including the Wapato, Toppenish, and Mabton areas; if all tributaries in an area have compound concentrations less than minimum reporting levels, then the load value is reported as less than (<); quantifiable loads exclude compound concentrations less than the minimum reporting level; DDT+DDE+DDD, 4,4'-dichlorodiphenyltrichloroethane (DDT) plus 4,4'-dichlorodiphenyldichloroethylene (DDE) plus 4,4'-dichlorodiphenyldichloroethane (DDD); EPTC, *S*-ethyl dipropylthiocarbamate; 2,4-D, (2,4-dichlorophenoxy) acetic acid]

Constituent	Instantaneous loads (grams per day) Kittitas area	Tieton area	East side	West side	Yakima River at Kiona
Suspended sediment[1]	42,000	1,200	320,000	60,000	110,000
Organochlorine compounds in unfiltered water (suspended plus dissolved phases[2])					
Chlordane	1.2	.08	.21	.76	<5.2
DDT+DDE+DDD	2.5	.30	58	9.0	55
Dieldrin	1.4	.08	26	.94	14
Endosulfan I	<.38	.34	6.2	.87	4.4
Organophosphorus compounds in unfiltered water (suspended plus dissolved phases[2])					
Chlorpyrifos	.09	<.39	.54	.55	35
Diazinon	<1.9	.66	120	56	140
Dimethoate[3]	<2.7	.46	210	3.1	<14
Malathion	<3.0	1.4	8.8	15	260
Parathion	<3.0	<.68	1.5	64.8	<12
Phorate	1.7	<.57	21	4.6	<10
Phosphamidon[1]	<2.3	.95	16	11	19
Thiocarbamate and sulfite compounds in filtered water					
EPTC	12	<.10	.84	3.5	12
Propargite	<2.7	<.41	200	47	26
Acetamide and triazine compounds in filtered water					
Alachlor	<1.1	<.23	24	26	44
Atrazine	32	.55	40	81	120
Metolachlor	<.89	<.20	<11	3.2	7.0
Prometon	3.2	2.0	20	.26	11
Simazine	4.9	.95	65	20	66
Chlorophenoxy-acid and benzoic compounds in filtered water					
2,4-D	89	<.81	90	35	330
Dicamba	49	<.81	13	<10	<37

[1]Suspended sediment loads are reported in kilograms per day.
[2]"Dissolved" refers to the filtrate that passes through a 1-micrometer pore-size filter.
[3]Dimethoate and phosphamidon were not analyzed for suspended sediment.

phthalate, naphthalene, and phenanthrene are semivolatile organic compounds that were detected in more than 30 percent of the samples. Semivolatile compound concentrations did not exceed the EPA interim sediment quality criteria for the protection of benthic fauna (U.S. Environmental Protection Agency, 1988). Concentrations of several organochlorine compounds generally exceeded the criteria in the agricultural areas, whereas relatively few exceedances were detected in the nonagricultural areas. DDT+DDE+DDD and dieldrin exceeded the criteria at most of the agricultural sites and, to a lesser extent, endosulfan I, endrin, and chlordane also exceeded the criteria. The detection of DDT+DDE+DDD and dieldrin in the bed sediment in the agricultural return flows generally coincided with the detection of these compounds in the water column.

Table 19. Number of sites and samples with organic compound concentrations that equaled or exceeded chronic-toxicity water-quality criteria for the protection of freshwater aquatic life, Yakima River Basin, Washington, 1988–91 water years

[DDT+DDE+DDD, 4,4'-dichlorodiphenyltrichloroethane (DDT) plus 4,4'-dichlorodiphenyldichloroethylene (DDE) plus 4,4'-dichlorodiphenyldichloroethane (DDD); PCB, polychlorinated biphenyls; 2,4-D, (2,4-dichlorophenoxy) acetic acid]

Compound	Chronic-toxicity water-quality criteria for freshwater aquatic life[1] (nanograms per liter)	Sites		Samples		
		Number sampled	Number of exceedances of criteria or guidelines	Number sampled	Number of exceedances of criteria or guidelines	Frequency of exceedance
Organochlorine compounds						
Chlordane (technical)	4.3	37	1	133	1	0.75
DDT+DDE+DDD	1.0	37	23	133	105	79
Dieldrin	1.9	37	14	133	65	49
Endosulfan I	56	37	3	133	8	6.0
Endrin	2.3	37	3	133	2	1.5
PCB	14	25	4	133	9	6.8
Toxaphene	.2	25	1	133	1	.75
Organophosphorus compounds						
Azinphos-methyl	10	18	[2]2	18	2	11
Diazinon	[3]9	37	18	133	55	41
Disulfoton	[3]50	33	1	57	2	3.5
Ethion	[3]20	37	2	133	7	5.3
Malathion	100	37	1	133	1	.75
Parathion	13	37	8	133	11	8.3
Phosphamidon	[3]30	29	3	29	3	10
Chlorophenoxy-acetic acid compound						
2,4-D	[3]3,000	31	1	106	1	.94

[1]U.S. Environmental Protection Agency, 1986.

[2]Two sites sampled by North Yakima Conservation District.

[3]Recommended maximum concentration sampled at any time and any place (National Academy of Science and National Academy of Engineering, 1973).

Concentrations of DDT+DDE+DDD in bed sediment samples collected upstream from nonagricultural areas in the Yakima River Basin ranged from <0.3 to 1.4 µg/kg (micrograms per kilogram). These lower concentrations suggest that the primary source of DDT+DDE+DDD in the nonagricultural areas is atmospheric deposition.

To explore relations among concentrations of organochlorine insecticides and other semivolatile compounds with agricultural activities, samples were collected from 3 agricultural fields and from 31 ditches. The bed sediment samples from the ditches were composited into seven samples by crop type. DDT+DDE+DDD was detected in ditches draining orchards or fields of apples, grapes, pears, and potatoes, but not of asparagus, corn, or hops. The soil samples analyzed were collected from two hop fields and one apple orchard. DDT+DDE+DDD was detected in both the A and B soil horizons in each of the soil samples; however, the data are limited in number and spatial coverage to be able to conclude an association between the crop type and amount of DDT+DDE+DDD contamination. The concentrations of DDT+DDE+DDD detected in the soil samples were, however, about four times higher than the concentrations of DDT+DDE+DDD in the suspended sediment and streambed sediment samples. Apparently, soil eroded from agricultural land was the major source of DDT+DDE+DDD to the streams. Because of the large reservoir of DDT+DDE+DDD in agricultural soils, the compounds are likely to be present in stream water and stream sediment for many decades.

Aquatic Biota

In 1989–90 WY, samples of fish, mollusks, and aquatic plants were collected from 33 sites for analyses of organic compounds. About two-thirds of these sites received agricultural return flow, point source discharges, and (or) urban runoff; the other sites were influenced minimally by human activity. Samples were analyzed for 25 organochlorine compounds and 14 polycyclic aromatic hydrocarbons (PAHs).

One DDT metabolite, 4, 4'-DDE[4], was the most widely detected organic compound in aquatic biota. This organochlorine compound was detected in fish samples at all sites sampled in 1989 and 68 percent of the sites in 1990. Other organochlorine compounds including DDT, DDD, dieldrin, *cis*-chlordane, and *trans*-nonachlor were each detected in samples from 32 percent or more of the sites. Dicofol, polychlorinated biphenyls (PCBs), toxaphene, and other chlordane related compounds were detected less frequently. The highest organochlorine compound concentrations generally were detected at main stem and tributary sites downstream from the city of Yakima, where agriculture was the primary land use.

Concentrations of DDT+DDE+DDD in resident fish from the Yakima River Basin were elevated relative to concentrations detected in national studies. When compared with data collected by U.S. Fish and Wildlife Service in 1984 through their National Contaminant Biomonitoring Program (NCBP) (Schmitt and others, 1990), the mean DDT+DDE+DDD concentration (1.12 µg/g [micrograms per grams], wet weight) in resident fish from the Yakima River Basin was more than four times the mean concentration measured in the NCBP. The mean DDE concentration (0.85 µg/g, wet weight) in resident fish from the Yakima River Basin was almost three times the concentrations measured by EPA in their National Study of Chemical Residues in Fish (NSCRF) (U.S. Environmental Protection Agency, 1992a). In the Yakima River Basin, dieldrin, *cis*-chlordane, *trans*-nonachlor, and toxaphene were also detected frequently with mean concentrations similar to those in the nationwide studies. Various individual samples from the Yakima River Basin, however, had higher concentrations. Concentrations of PCBs and total chlordane related compounds, although frequently detected in Yakima River Basin samples, were generally lower than concentrations detected in the nationwide studies.

In this study, wet weight concentrations of most organochlorine compounds in whole fish correlated significantly with lipid concentrations in the fish, suggesting that concentrations of these compounds accumulate in or are controlled by fish lipids. This relation was evaluated further by normalizing organochlorine compound concentrations for lipid concentrations in samples of smallmouth bass (*Micropterus dolomieu*), mountain whitefish (*Prosopium williamsoni*), largescale sucker (*Catostomus macrocheilus*), and Asiatic clams (*Corbicula fluminea*) collected from a Yakima River site near the terminus of the basin. After normalization, DDT+DDE+ DDD concentrations were similar among the four species, ranging from 20 to 26 µg/g-lipid (fig. 24).

In the Yakima River Basin, most samples of resident fish collected downstream from the city of Yakima had concentrations of DDT+DDE+DDD, PCBs, chlordane related compounds, dieldrin, toxaphene, and PAHs higher than concentrations expected to result in an increased lifetime cancer risk of 1:1,000,000 (1 in 1 million) (Rinella and others, 1993). The highest increased cancer risk was computed to be 600:1,000,000 and was based on the detection of high PCB concentrations in resident fish (largescale sucker and mountain whitefish) from the Yakima River at Kiona. Although these results indicate possible human health effects from eating certain species of resident fish in the Yakima River Basin, several caveats must be considered: (1) in this study, whole fish, not just the edible portions, were analyzed, so the data may not be representative of what people are consuming, (2) different species may accumulate different amounts of contaminants, so the fish and associated contaminants that people are consuming may not be represented in this study, (3) the higher contaminant concentrations were detected primarily in the Lower Valley downstream from the city of Yakima,

[4] For aquatic biota samples, both the 2, 4'- and 4, 4'-isomers of DDT, DDE, and DDD were determined. For water and sediment samples, however, only the 4, 4'-isomers were determined.

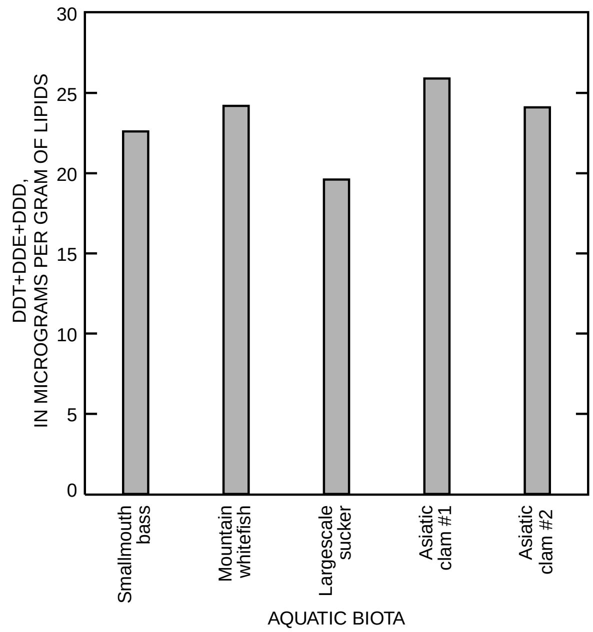


Figure 24. Lipid-normalized concentrations of dichlorodiphenyltrichloroethane (DDT) plus dichlorodiphenyldichloroethylene (DDE) plus dichlorodiphenyldichoroethane (DDD) in fish and mollusk samples from the Yakima River at Kiona, Washington, October 1989. (DDT+DDE+DDD, the sum of 2,4'-DDT, 4,4'-DDT, 2,4'-DDE, 4,4'-DDE, 2,4'-DDD, and 4,4'-DDD.)

and (4) seasonal variations in contaminant concentrations in biota were not determined in this study.

Recommended concentrations for contaminants in fish to protect fish-eating predators (National Academy of Sciences and National Academy of Engineering, 1973) were exceeded in some samples for four pesticides: DDT+DDE+DDD, chlordane, dieldrin, and toxaphene. Mean concentrations of DDT+DDE+DDD and toxaphene in the Yakima River Basin fish samples exceeded the NAS-NAE guidelines. Seventeen fish samples and two mollusk samples had concentrations of DDT+DDE+DDD that exceeded NAS-NAE guidelines for the protection of fish predators (guideline of 1.0 µg/g, wet weight). The highest concentration of DDT+DDE+DDD (4.9 µg/g, wet weight) occurred in Sulphur Creek Wasteway, a major agricultural return flow near Sunnyside. Upstream from the city of Yakima, NAS-NAE guidelines were not exceeded in the resident fish samples. As a result of the DDT+DDE+DDD concentrations measured during this study, the Washington Department of Health (1993) issued a recommendation to "eat fewer bottom fish," particularly largescale sucker, bridgelip sucker, and mountain whitefish, from the Yakima River Basin, particularly from "the lower Yakima River and agricultural drains, from the city of Yakima to the Columbia River."

Naphthalene, fluoranthene, phenanthrene, and benzo(*e*)pyrene were the most frequently detected PAHs found in the biological samples collected from the Yakima River downstream from the city of Yakima. Only two carcinogenic PAHs were detected in this study, chrysene in a waterweed sample from Satus Creek and 1,2-benzanthracene in an Asiatic clam sample from Yakima River at RM 72, both at the minimum reporting level of 0.01 µg/g, wet weight.

Occurrence of Organic Compounds Among Various Sampling Media

In aquatic environments, organic compounds partition among water (dissolved phase), dissolved organic carbon (dissolved and colloidal phases), particulate organic carbon (soils, suspended sediment, and bed sediment), and the lipids of aquatic biota. In this study, organochlorine compounds were detected in all environmental compartments sampled, including water, suspended sediment, bed sediment, aquatic biota, and soils, whereas PAHs were analyzed and detected only in bed sediment and aquatic biota. Carbamate compounds, chlorophenoxy acid herbicides, organophosphorus compounds, and triazine herbicides have relatively high water solubilities and low K_{oc} values, so these compounds were analyzed primarily in filtered water, where many were detected.

To determine the relations among sampling media, concentrations of DDT+DDE+DDD and dieldrin were chosen because they were detected frequently throughout the Yakima River Basin. For these determinations, contaminant concentrations in sediment were normalized to organic carbon and concentrations in aquatic biota were normalized to lipid content. Results indicate that increased concentrations of DDT+DDE+DDD and dieldrin in filtered water, unfiltered water, or bed sediment were associated with increased concentrations of these compounds in aquatic biota. For DDT+DDE+DDD and dieldrin, contaminant concentrations associated with suspended sediment were generally higher than those in bed sediment. Overall, consistent results among the sampling media provide multiple lines of evidence of pesticide occurrence and indicate that contaminant concentrations in one sampling medium could be used to estimate contaminant concentrations in another medium.

Sampling media were also evaluated to determine which medium would be best suited for detecting the low level occurrence of organochlorine compounds: aquatic biota having varying concentrations of lipids, bed sediment, 1-L volumes of unfiltered water (conventional analyses), large volumes of filtered water (up to 120 L), or large amounts of suspended sediment from sample volumes up to 224 L. Overall, analyses of bed sediment and aquatic biota showed that they were the most sensitive sampling media for detecting hydrophobic compounds. At a particular sampling site, a contaminant generally was detected in both the bed sediment and the biota, if the biota sample had a lipid concentration of about 6 percent or more (for example, lipid concentrations typically detected in largescale sucker, mountain whitefish, and chiselmouth from the Yakima River Basin). The least sensitive medium for detecting low level concentrations of organochlorine compounds was aquatic plants, probably because plants have low lipid concentrations, about 0.2 percent. At two of the sites, PCB and toxaphene were detected in fish tissue samples, but were not detected in bed sediment. At these sites, concentrations in the whole fish exceeded EPA health advisory estimates for an increased lifetime cancer risk of more than 1:1,000,000. For assessment purposes, it may be advantageous to analyze tissue samples rather than bed sediment samples, because tissue analyses provide a direct measure of bioavailability and may be used for determining critical routes of contaminant exposure to fish predators, including humans. Fish, however, are mobile, which makes it difficult to use tissue data to identify whether the contaminant source is upstream or downstream from the sampling site. In contrast, the source of bed sediment contamination is generally at or upstream from the sampling location.

Implications for Water Resource Monitoring and Regulation

Pesticides that most frequently exceeded EPA chronic-toxicity water-quality criteria or NAS-NAE guidelines for the protection of freshwater aquatic life in June 1989 included DDT+DDE+DDD, dieldrin, diazinon, and parathion. Reductions in pesticide concentrations that were needed to meet criteria or guidelines for DDT+DDE+DDD, dieldrin, diazinon, and parathion ranged from 29 to 99 percent at 18 of 29 sites, 47 to 95 percent at 7 sites, 31 to 98 percent at 14 sites, and 19 to 93 percent at 4 sites, respectively. Assuming that instream contaminant concentrations during the irrigation season can be reduced, by controlling erosion and overland runoff, to the concentrations expected during a period of minimal overland runoff, parathion and diazinon would then meet guidelines. Dieldrin and DDT+DDE+DDD would meet guidelines in the main stem, but still exceed guidelines in the agricultural return flows by as much as 3 ηg/L and 18 ηg/L, respectively.

Results showed a clear seasonal increase in stream concentrations of hydrophobic and hydrophilic pesticides at or near peak irrigation periods when pesticides were flushed and (or) eroded with soils from agricultural fields. Pesticide concentrations also increased during stormwater runoff from agricultural areas in the winter and summer months.

The flushing of compounds from soil-pore water, the eroding of soil-sorbed compounds, and the dissolving of compounds from soil and sediment into surface water are major pathways for pesticides to travel from agricultural fields to streams and aquatic biota. Controlling applications of excessive irrigation water will help to reduce overland runoff and, therefore, the subsequent dissolution, erosion, and (or) transport of pesticides to streams. If management decisions are made to reduce overland runoff, ground-water quality could be monitored to ensure that pesticide concentrations do not increase in the aquifers. As surface-water runoff is reduced from agricultural land, pesticide concentrations could also be monitored in the agricultural return flows to ensure that concentrations are not increasing and causing short term, localized, surface-water-quality concerns.

Data from the Yakima River Basin indicate that increases in pesticide use generally coincide with increases in the number of pesticide detections in streams. This relation seems obvious, however, research analyses in this study were required to be able to detect many of the currently used pesticides at concentrations below 100 ηg/L.

Using pesticides with one or more of the following characteristics will minimize the likelihood of transport from agricultural fields to streams:

1. Half-lives in soils and water of less than 3 weeks, to increase the likelihood of the compounds to degrade in the fields prior to stream transport;

2. Water solubilities less than 30 mg/L, to minimize dissolution and flushing of pesticides from soils; and

3. K_{oc} values larger than 500 mL/g, to increase the likelihood of the pesticide to remain sorbed to agricultural soils.

Methods of irrigation can greatly influence the degree of overland runoff and erosion, which subsequently influences pesticide transport to streams. Of the four types of irrigation methods used in the Yakima River Basin (rill, flood, sprinkler, and drip), drip (above and below land surface) irrigation is the most effective method for reducing erosion and overland runoff, because a minimum amount of water is applied to the land surface and subsurface soils in the root zone. Other factors that affect pesticide transport to streams include (1) timing of irrigation and storm runoff relative to pesticide application and the likelihood for increased overland runoff, (2) location of pesticide application relative to the potential for stream contamination, (3) method of pesticide application (ground vehicle sprays, aerial sprays, and chemigation), and (4) use of grass cover crops to help hold the soil in place.

Better understanding the occurrence, distribution, sources, transport, fate, and effects of organic compounds in the Yakima River Basin would benefit from:

- Analyses for more pesticides and their breakdown products at lower minimum reporting levels—In this study, about 70 percent of the 180 compounds applied in 1989 were not analyzed. Therefore, ecological consequences for more than 120 of these compounds in water, sediment, and aquatic biota in the Yakima River Basin have not been identified.

- Increased temporal coverage for sampling organic compounds in water, sediment, and aquatic biota—To better understand major sources and potential effects on aquatic biota, the variations (duration and range) in seasonal concentrations must be better understood. For example, weekly, daily, and (or) hourly sampling during selected periods when concentrations and temporal variability are expected to be high (for example, irrigation season or storm runoff following pesticide application).

- Increased spatial coverage for determining the occurrence of organic compound concentrations in water, bed sediment, aquatic biota, and soils and the processing of these compounds within and among these media—Identify major sources of organic compounds in order to model and assess cause and effect processes and pesticide transport in the basin.

- Relating pesticide loads to contributing factors, including crop types, soil characteristics, basin characteristics, and farming practices (pesticide application, irrigation, cover crop usage, and cultivation methods). Better quantification of these factors would provide managers with valuable information for improving and (or) maintaining good water-quality conditions in the basin.

- Research to determine the effectiveness of erosion controls for reducing concentrations of dissolved and suspended organic compounds in streams.

- Bioassays using native water, native sediment, and appropriate sensitive test organisms to help determine potential additive or synergistic effects.

- Research to determine the synergistic effects of multiple toxic compounds and elements at high water temperatures on aquatic life.

- Accurate information about the quantity of pesticides applied in the Yakima River Basin.

Trace Elements

By Gregory J. Fuhrer

This section is a synthesis of two interpretative reports (Fuhrer, McKenzie, and others, 1994; Fuhrer and others, 1998). Data and quality assurance results for the interpretative reports are published in Ryder and others (1992) and Fuhrer, Fluter, and others (1994). The first of the interpretative reports (Fuhrer, McKenzie, and others, 1994) is an analysis of major and trace elements in fine-grained (less than 63 µm [micrometers] in diameter) streambed sediment samples collected from 407 sites in the Yakima River Basin in 1987. Sampling sites for lower order streams[5] were selected using a sampling design in which sites were randomly selected from a "square sample grid" (4.7 miles per side) placed over a 1:24,000-scale base map; 270 of the 332 lower order stream sites were located in this manner. Sites not randomly sampled were intentionally selected and sampled for quality assurance purposes. Higher order stream sites were not randomly sampled, but were intentionally located along streams draining to major tributaries, at mouths of major tributaries, and along the main stem; 65 sites were located in this manner. Additionally, soil samples were collected at four sites within agricultural plots, some of which had been formerly treated with the lead arsenate pesticide. Six urban stormwater drains also were sampled.

The second of the interpretative reports (Fuhrer and others, 1998) is an analysis of major and trace elements in several media, including streambed sediment, suspended sediment, water (filtered and unfiltered water samples), and aquatic biota. Streambed sediment sampling was limited, however, and covered only 32 sites corresponding to sites sampled for aquatic biota in the 1989–91 WY. The fixed sites also were sampled for elements in aquatic biota, suspended sediment, and water on a monthly basis and during several hydrologic conditions during the 1987–91 WY. Trace elements were measured in filtered water samples collected at least once at 44 sites, with most of these sites sampled over a period of 1 to 2 weeks in July and (or) November 1987. Unfiltered water samples for the analysis of trace elements generally were collected on a quarterly basis at the fixed sites during 1987.

[5] In this report, lower order streams are defined as first or second order tributaries, and higher order streams are defined as third order or larger tributaries—the largest being the main stem of the Yakima River. The smallest, unbranched, mapped (1:24,000-scale map) tributaries are first order tributaries. Streams receiving only first order tributaries are second order tributaries, larger streams receiving only first and second order tributaries are third order, and so on (Horton, 1945).

Effects of Geology on Chromium Concentrations

Most element enrichment in the Yakima River Basin resulted from natural geologic sources underlying forest lands of the Kittitas and Mid Valleys, primarily in the Cle Elum, Upper Naches, Teanaway, and Tieton Subbasins (fig. 1). These areas might be classified as "pristine" by the casual observer; however, they are geologic sources of antimony, arsenic, chromium, copper, mercury, nickel, selenium, and zinc. For example, in the Kittitas Valley, arsenic, chromium, and nickel concentrations in streambed sediment affected by geologic sources were as high as 61, 1,700, and 1,900 µg/g, respectively. These elevated concentrations ranged from 13 to 74 times higher than the respective median concentrations in streambed sediment from the Lower Valley in agricultural areas unaffected by geologic sources. The pre-Tertiary metamorphic and intrusive rocks were the source of high chromium concentrations in the Kittitas Valley (fig. 25); high trace element concentrations in the pre-Tertiary rocks were typical for arsenic, cobalt, and nickel, as well. The pre-Tertiary rocks include portions of the Cle Elum and Teanaway Subbasins, where several sites have high chromium concentrations that exceeded the 95-percent range of concentrations in Western United States soils (table 20).

As a result of geologic sources, several of these elements, including arsenic, chromium, copper, and nickel, left chemical signatures measurable in streambed sediment and suspended sediment of higher order streams. For example, chromium concentrations in streambed sediment in the Yakima River at Cle Elum, a fixed site located near the geologic source, exceeded 200 µg/g (fig. 26). Downstream, however, concentrations decreased to 64 µg/g in the Yakima River at Umtanum as a result

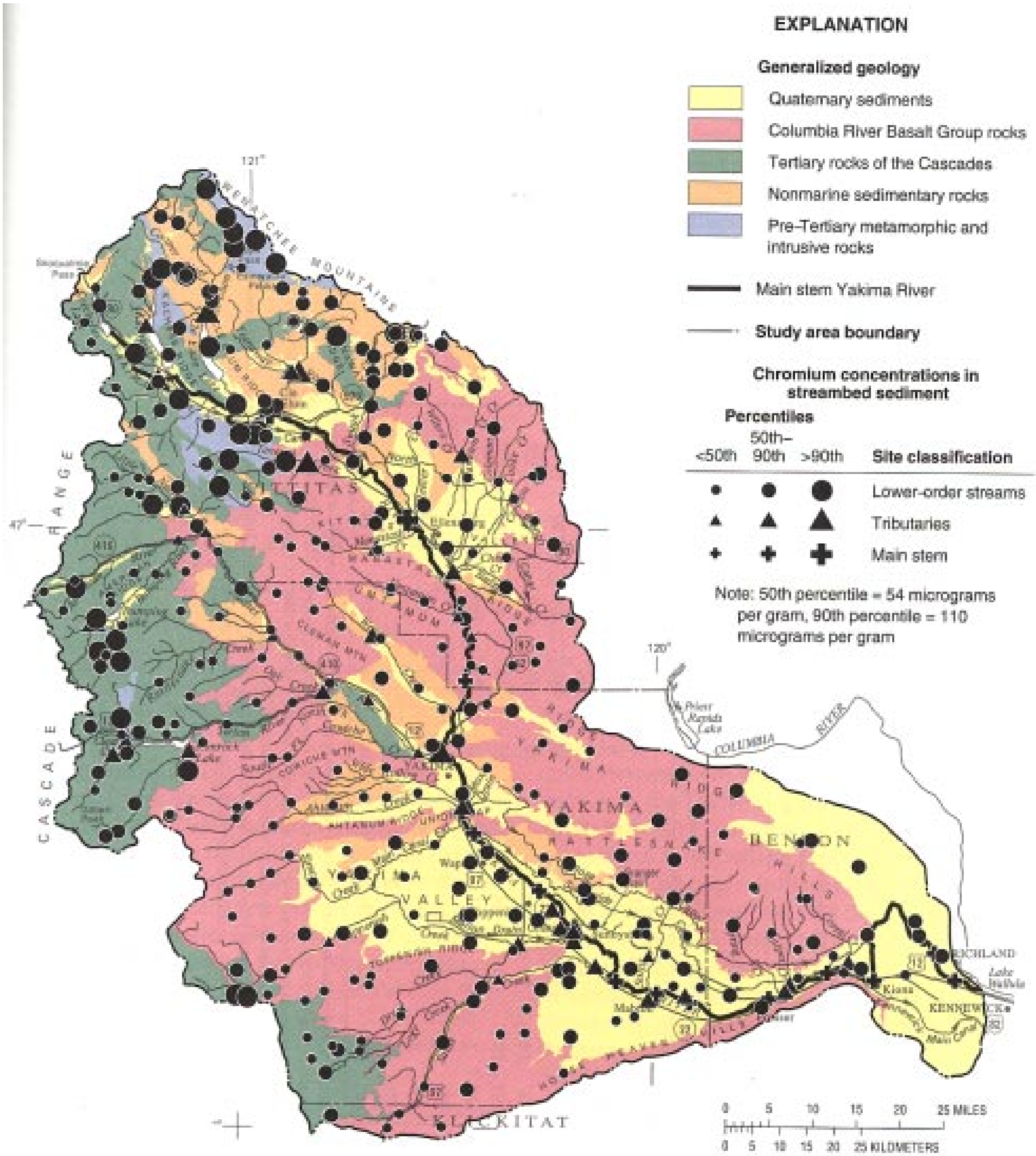


Figure 2 5 . Distribution of chromium concentrations in streambed sediment, Yakima River Basin, Washington, 1987.

Table 20. Statistical distribution of selected elements in fine-grained streambed sediment of the Yakima River Basin, Washington (1987), and in soils of the Western United States

[Fine-grained streambed sediment refers to that fraction of the sample less than 63 micrometers in diameter; the soils data is based on bulk samples; to avoid statistical bias that may be associated with elements analyzed more than once at a site, only one concentration per site was statistically summarized; concentrations are reported as micrograms per gram, dry weight; data statistically summarized in this table are from Fuhrer and others (1998); concentrations shown in **bold** print equal or exceed baseline concentrations for the Yakima River Basin; na, not analyzed; < , less than]

Element	Yakima River Basin streambed sediment (1987)										Western United States soils[1]		
	Number of sites	Minimum concentration	Concentration at indicated percentile						Maximum concentration	Baseline concentration[2]	Number of observations	Expected 95% range for baseline soils[3]	Maximum concentration
			10	25	50	75	90	98					
Antimony	404	0.1	0.2	0.3	0.4	0.5	**0.8**	**2.0**	**4.8**	0.7	na	na	na
Arsenic	404	.7	1.6	2.3	3.9	5.9	**11**	**66**	**310**	8.5	730	1.2–22	97
Beryllium	407	<1	<1	<1	<1	2	2	2	**4**	3	778	.13–3.6	15
Cobalt	407	10	15	17	20	24	30	**57**	**140**	40	778	1.8–28	50
Cerium	407	5	33	39	45	56	**69**	**100**	**120**	57	683	22–190	300
Chromium	407	14	32	44	54	74	110	**554**	**1,800**	320	778	8.5–200	2,000
Copper	407	13	20	24	28	34	**46**	**96**	**190**	40	778	4.9–90	300
Lead	407	2	9	11	13	17	**25**	**130**	**890**	20	778	5.2 – 55	700
Mercury	406	<.02	<.02	<.02	.02	.08	.16	**.48**	**3.1**	.30	733	.008–.25	4.6
Nickel	407	4	13	17	21	32	53	**690**	**1,900**	120	778	3.4–66	700
Selenium	99	<.1	<.1	.2	.4	.6	**1**	**1.3**	**1.4**	.7	733	.04–1.4	4.3
Zinc	407	32	71	80	93	110	**130**	**220**	**710**	120	766	17–180	2,100

[1]Soils data may offer a regional perspective or framework for assessing Yakima River Basin streambed sediment chemistry. Several noteworthy limitations apply when making comparisons between soils and streambed-sediment data—see Fuhrer and others (1998) for further discussion.

[2]The term baseline was applied to a concentration that separates an upper or anomalous data set from a lower or background data set. The derivation of baseline concentrations referenced in this report are detailed in Fuhrer and others (1998).

[3]Range of concentrations encompassing 95 percent of Western United States soils (R.C. Severson, U.S. Geological Survey, written commun., 1987, based on data in Shacklette and Boerngen, 1984). Soils data are provided as an ancillary data set that may offer a regional perspective.

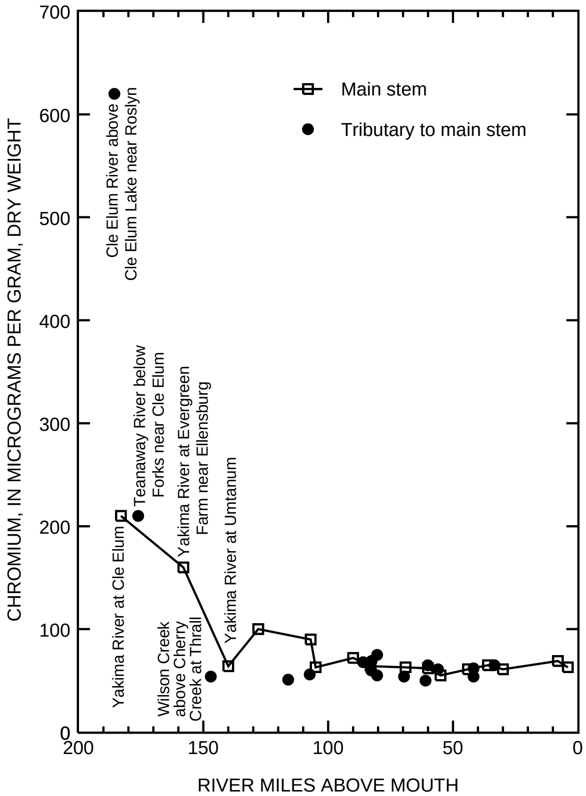


Figure 26. Chromium concentrations in streambed sediment of the main stem and selected tributaries, Yakima River Basin, Washington, 1987.

of dilution by the chromium-poor sediment from Wilson Creek. Sediment in the Wilson Creek drainage originated from Quaternary deposits and loess, where the median chromium concentration was only 56 µg/g. The spatial distribution of suspended chromium concentrations was similar to that in streambed sediment. Concentrations of chromium in suspended sediment, measured monthly and during hydrologic events during the 1987–91 WY, ranged from 28 to 160 µg/g (table 21), with the highest concentrations measured in the Kittitas Valley.

The seasonal variation in suspended chromium concentrations in the Yakima River at Umtanum (fig. 27) was indicative of seasonal changes in the source and quantity of water at this site. The chromium-rich sediment of the pre-Tertiary metamorphic and intrusive rocks in the Cle Elum Subbasin contributed large concentrations of suspended chromium during both the snowmelt and much of the irrigation seasons at Umtanum (fig. 27). The concentrations of suspended chromium decreased sharply, however, in the late irrigation season (September and October) coinciding with the curtailment of reservoir releases upstream from Umtanum, including releases from Cle Elum Lake. This reduction of streamflow indirectly increased the proportion of irrigation return flow at Umtanum—an important factor because the agriculturally affected sediment entering the main stem in the irrigation return flow upstream from Umtanum was formed in the chromium-poor Quaternary deposits and loess. The net result of this increase in the proportion of chromium-poor sediment entering the main stem was the dilution of the suspended chromium concentrations during September and October. Similar temporal patterns also existed for suspended arsenic and nickel concentrations.

In addition to measurable concentrations in streambed and suspended sediments, some of the geologically derived elements, including chromium, nickel, and selenium, also were detected in the aquatic biota of the higher order streams. For example, chromium concentrations in aquatic insects in the North Fork of the Teanaway River ranged from 2.2 to 33 µg/g and were 4 to 52 times higher (depending on the species) than the minimum concentrations measured in the basin. Enrichment from the Teanaway River also affected, to a lesser extent, the Yakima River at Umtanum and was evident in caddisflies, stoneflies, curlyleaf pondweed, and suspended sediment (table 22). The sharp contrast between the high chromium concentrations in the main stem at Umtanum and the low chromium concentrations in Umtanum Creek (a reference site) underscores the effect of the geologic distribution of trace elements among media. Umtanum Creek drains the chromium-poor Columbia River Basalt Group rocks, where the median chromium concentration was only 48 µg/g. Low chromium concentrations also were found in Rattlesnake Creek in the Naches Subbasin, Yakima River at RM 72, and several other agriculturally affected tributaries (table 22). Chromium concentrations in fish and Asiatic clams in the Lower Valley and tributaries of the Mid Valley were typically small (<2 µg/g) and varied little among sites. Although geologic sources affected aquatic biota in some lower and higher order streams, the influences

Table 21. Statistical distribution of trace element concentrations in suspended sediment at fixed sites, Yakima River Basin, Washington, 1987–91 water years

[To avoid statistical bias that may be associated with constituents analyzed more than once at a site, only one concentration per visit was statistically summarized; see table 3 for identification of fixed sites; concentrations are reported as micrograms per gram, dry weight; <, less than]

Element	Number of samples	Minimum concentration	Concentration at indicated percentile						Maximum concentration
			10	25	50	75	90	95	
Antimony	211	0.3	0.5	0.5	0.6	0.7	0.8	0.9	3.1
Arsenic	211	2.8	4.7	5.4	6.6	8.2	11	14	20
Beryllium	211	<2	<2	<2	<2	<2	2	2	3
Cadmium	211	<.1	.2	.3	.5	.7	1.4	1.7	32.6
Chromium	184	28	46	55	60	83	110	120	160
Copper	211	21	33	39	44	55	74	96	680
Lead	211	6	12	15	19	24	27	30	410
Nickel	184	12	22	29	37	55	82	105	170
Silver	211	<.1	.2	.2	.4	.5	.9	1.3	7.7
Zinc	184	88	112	123	142	172	202	231	521

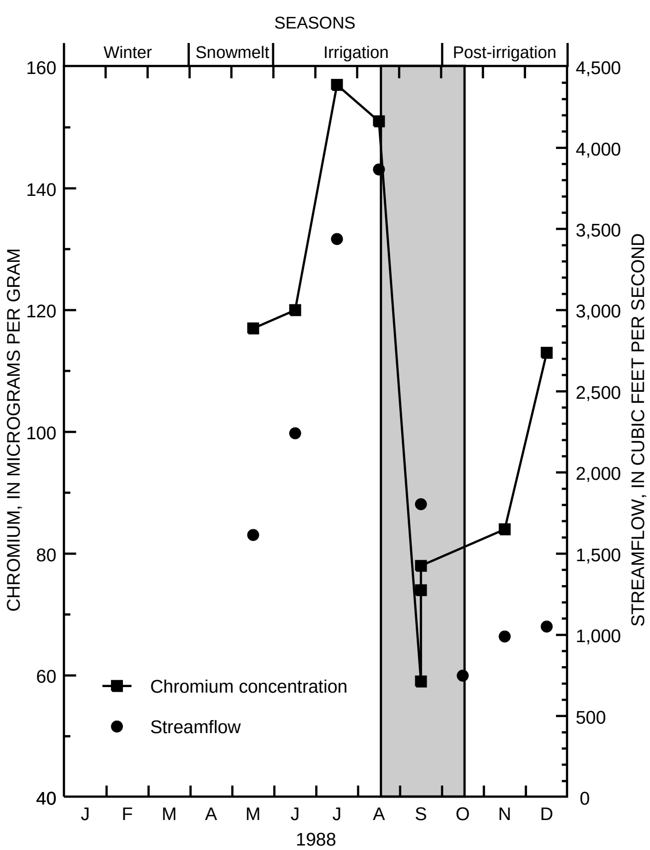


Figure 27. Monthly chromium concentrations in suspended sediment and mean monthly streamflow in the Yakima River at Umtanum, Washington, 1988. (The shaded area represents the period of time when streamflow is reduced from reservoirs upstream from the Yakima River at Umtanum.)

of these sources were offset by the diluting effect of other chromium-poor geologic units. Consequently, the median concentration of chromium (1.7 μg/g) in benthic insects in the Yakima River Basin was less than the concentrations of chromium reported for benthic insects in uncontaminated to minimally contaminated basins in other studies (Elwood and others, 1976; Lynch and others, 1988; Smock, 1983).

Combined Effects of Geology and Irrigation Return Flow on Selenium Concentrations

The distribution of selenium concentrations was affected principally by the Miocene and older volcanic rocks, marine sedimentary rocks, and pre-Tertiary metamorphic and intrusive rocks located in the forests of the Cascades. Selenium concentrations in streambed sediment at several sites in these geologic units were two to three times the median concentration (0.4 μg/g) in the basin. The geologically affected selenium concentrations in the streambed sediment of the forest lands also resulted in high selenium concentrations in whole sculpins (*Cottus* spp.). Selenium concentrations in sculpin ranged from 0.2 to 5.4 μg/g, dry weight, and were high in Rattlesnake Creek in the Naches Subbasin and nearby Taneum Creek. Concentrations of selenium in sculpin also were higher at sites located near the mouths of creeks carrying irrigation return flow than at sites located upstream from agricultural activity. For example, 2.6 μg/g of selenium was measured in whole sculpin

Table 22. Comparison of low, medium, and high chromium concentrations in water, sediment, and aquatic biota for selected sites, Yakima River Basin, Washington, 1987–91 water years

[This table is a partial listing of table 23 in Fuhrer and others, 1998; for filtered water, the concentration rankings are based on a percentile distribution of the 75th-percentile values for each fixed site; for streambed sediment and aquatic biota, the concentration rankings are based on a percentile distribution of the mean concentrations for each fixed site; for suspended sediment, the concentration rankings are based on a percentile distribution of the 50th-percentile values (median) for each fixed site; see table 3 for identification of fixed sites; high concentrations (H) represent that portion of the distribution which is greater than or equal to the 75th-percentile value; low concentrations (L) represent that portion of the distribution which is less than or equal to the 25th-percentile value; concentrations greater than the 25th, but less than the 75th-percentile value are considered medium (M); only 1990 data are summarized for largescale sucker livers and caddisflies; sample species: largescale sucker (*Catostomus macrocheilus*), caddisfly (*Hydropsyche* spp.), stonefly (*Hesperoperla* sp.), Asiatic clam (Veneroida: Corbiculidae *Corbicula fluminea*), and curlyleaf pondweed (*Potamogeton crispus*); --, no data]

Site name	Filtered water	Sediment		Aquatic biota				
		Streambed	Suspended	Largescale sucker liver	Insects: Caddisfly	Insects: Stonefly	Asiatic clam	Curlyleaf pondweed
Kittitas Valley								
Jungle Creek near mouth near Cle Elum	--	H	--	--	--	--	--	--
North Fork Teanaway River	--	--	--	--	--	H	--	--
Teanaway River below Forks near Cle Elum	--	H	--	--	--	--	--	--
Yakima River at Cle Elum	H	H	H	--	M	M	--	--
Taneum Creek at Taneum Meadow near Thorp	--	H	--	--	--	M	--	--
South Fork Manastash Creek near Ellensburg	--	H	--	--	--	M	--	--
Mid Valley								
Yakima River at Umtanum	L	--	H	--	H	H	--	H
Umtanum Creek near mouth at Umtanum	--	L	--	--	L	--	--	--
Rattlesnake Creek above Little Rattlesnake near Nile	--	L	--	--	L	L	--	--
Wide Hollow Creek near Ahtanum	--	L	--	--	L	--	--	--
Lower Valley								
Yakima River at river mile 72 above Satus Creek	--	M	--	--	--	--	L	L
Yakima River at Kiona	H	M	M	M	M	--	M	M

from Ahtanum Creek at Union Gap, located near the mouth of Ahtanum Creek and receiving irrigation return flow from the Ahtanum Creek Subbasin. In contrast, concentrations of selenium in sculpin found upstream from the agricultural activity on Ahtanum Creek were only 1.0 µg/g. Similar concentration gradients also existed in the Satus Creek drainage. The concentration of selenium (31 µg/g) in a rainbow trout liver sample from Wide Hollow Creek, a creek affected by agricultural and urban activities, was four to eight times higher than these concentrations in rainbow trout from other sites in the basin. Although few filtered water samples collected in the basin were analyzed for selenium, two of the three samples collected from Sulphur Creek had detectable selenium concentrations (1 and 2 µg/L [micrograms per liter]).

Effects of Past and Present Human Activities on Arsenic and Lead Concentrations

In some parts of the basin, human activities (such as farming) reduced element concentrations, whereas at other locations, these activities increased element concentrations. Elements whose concentrations increased in areas affected by human activities include antimony, cadmium, copper, lead, mercury, selenium, and zinc. Concentrations of these elements were frequently highest in the Wide Hollow Creek Subbasin, which drains urbanized and lightly industrialized lowland in addition to agricultural land in the upper reaches of the subbasin. Concentrations of lead in streambed sediment of Wide Hollow Creek, for example, were more than twice that expected from the geologic sources in Wide Hollow Creek Subbasin. These concentrations also exceeded the 5.2 to 55 µg/g range of concentrations found in 95 percent of the Western United States soils (table 20).

In addition to urban runoff, previous applications of lead arsenate in apple orchards also may have been a source of lead, as well as arsenic. Prior to 1955, approximately 3,000 acres of apple orchards existed, primarily in the Mid and Lower Valleys (U.S. Department of Agriculture, 1986). The pesticide lead arsenate was applied to control codling moths in apples in eastern Washington beginning in 1908, and this practice continued until the introduction of DDT in 1947. From 1908 to 1947, lead arsenate applications increased from 50 lb (pounds) of lead and 18 lb of arsenic, to 192 lb of lead and 71 lb of arsenic per acre (Peryea, 1989). In the Mid Valley, concentrations of lead in the soils of former apple orchards historically treated with lead arsenate were as high as 890 µg/g, dry weight. Antimony concentrations in these treated soils were as high as 2.9 µg/g, dry weight. The relation between the elevated lead and antimony concentrations was probably a result of the pesticide formulation—lead produced from domestic sources contained residual antimony (U.S. Geological Survey, 1969). Additionally, a significant Kendall's tau-b correlation ($p=0.03$, $n=77$) between lead and arsenic further supports the presence of a historical lead arsenate source in the agricultural lands of the Lower Valley.

While arsenic enrichment in the Kittitas Valley resulted from natural geologic sources, human activities increased arsenic concentrations in filtered water, suspended sediment, and aquatic biota in the Mid and Lower Valleys. Agricultural drains were useful as indicators of past arsenic use. Concentrations of arsenic in suspended sediment, measured monthly and during hydrologic events during the 1987–91 WY, ranged from 4.9 to 20 µg/g in Sulphur Creek Wasteway and were the highest in the basin. During the irrigation season in particular, about 2.2 lb of suspended arsenic per day entered the Mid Valley within a 9.4-mile reach that includes irrigation return flow from the Moxee and Wide Hollow Subbasins. This arsenic load represented about one-half the irrigation season's daily mean load at Union Gap. Moxee Drain is estimated to contribute nearly 1 lb of suspended arsenic per day during the irrigation season. In the Lower Valley, the June contributions of suspended arsenic from Sulphur Creek Wasteway (2 lb/day) typically accounted for most of the suspended arsenic load at Grandview.

Filtered water samples, collected monthly at the fixed sites during the 1987–91 WY, had arsenic concentrations ranging from <1 to 9 µg/L (table 23). Arsenic concentrations were higher in the Mid and Lower Valley, where the waters were affected primarily by agricultural return flow (table 24). Median arsenic concentrations in Sulphur Creek Wasteway and in the main stem of the Lower Valley exceeded the median for the basin (<1 µg/L).

Table 23. Statistical distribution of trace element concentrations in filtered water samples at fixed sites, Yakima River Basin, Washington, 1987–91 water years

[To avoid statistical bias that may be associated with constituents analyzed more than once at a site, only one concentration per visit was statistically summarized; see table 3 for identification of fixed sites; concentrations are reported in micrograms per liter; <, less than]

Element	Number of samples	Minimum concentration	Concentration at indicated percentile					Maximum concentration
			10	25	50	75	90	
Antimony	18	<1	<1	<1	<1	<1	<1	1
Arsenic	119	<1	<1	<1	<1	2	3	9
Beryllium	36	<.5	<.5	<.5	<.5	<.5	<.5	<.5
Cadmium	279	<.2	<.2	<.2	<.2	<.2	.3	2.2
Chromium	26	<.5	<.5	<.5	<.5	.6	1.0	1.1
Copper	280	<.5	<.5	.6	.9	1.3	1.9	20
Lead	279	<.5	<.5	<.5	<.5	<.5	<.5	1.9
Mercury	283	<.1	<.1	<.1	<.1	<.1	<.1	.6
Nickel	36	<10	<10	<10	<10	<10	<10	<10
Selenium	22	<1	<1	<1	<1	<1	<1	2
Zinc	36	<3	<3	<3	5	12	18	30

Table 24. Statistical distribution of arsenic concentrations in filtered water samples at fixed sites, Yakima River Basin, Washington, 1987–91 water years

[To avoid statistical bias that may be associated with constituents analyzed more than once at a site, only one concentration per visit was statistically summarized; concentrations are reported in micrograms per liter; <, less than; see table 3 for full site names]

Site name	Number of samples	Minimum concentration	Concentration at indicated percentile					Maximum concentration
			10	25	50	75	90	
Cle Elum	16	<1	<1	<1	<1	<1	<1	<1
Umtanum	11	<1	<1	<1	<1	<1	<1	<1
Naches	15	<1	<1	<1	<1	<1	<1	1
Union Gap	23	<1	<1	<1	<1	<1	<1	1
Sulphur Creek	15	2	2	2	3	7	8	9
Grandview	14	<1	<1	<1	1	2	2	3
Kiona	25	<1	<1	1	1	2	3	4

Concentrations of arsenic in Sulphur Creek Wasteway ranged from 2 to 4 µg/L during the irrigation season and from 7 to 9 µg/L during the nonirrigation season.

Although arsenic concentrations at the Sulphur Creek site were lower during the irrigation season than during nonirrigation periods, concentrations were generally similar to the higher arsenic concentrations measured at the Grandview and Kiona sites during the irrigation season (fig. 28). These increases in arsenic concentrations at the Grandview and Kiona sites coincided with decreased streamflows in the main stem and probably resulted from dilution processes—higher concentrations of arsenic were generally associated with decreased streamflows and conversely, low concentrations of arsenic were generally associated with increased streamflows. Arsenic concentrations in Sulphur Creek Wasteway, and possibly in other tributaries that carried irrigation return flow (although not measured in this study), are important sources of arsenic in the main stem. The effect of these sources of arsenic is especially important during the irrigation season, because a majority of the streamflow in the main stem of the lower Yakima Valley is irrigation return flow (Rinella, McKenzie, Crawford, and others, 1992).

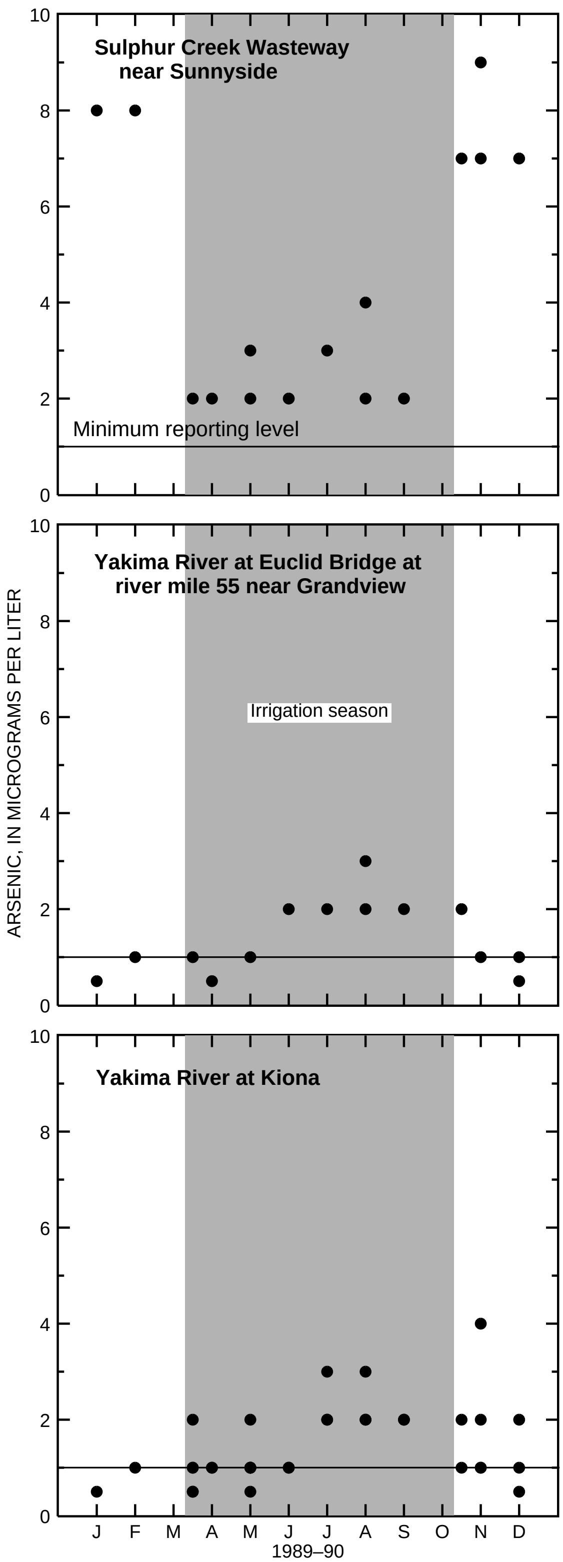


Figure 28. Arsenic concentrations in filtered water samples at Sulphur Creek Wasteway near Sunnyside, the Yakima River at Euclid Bridge at river mile 55 near Grandview, and the Yakima River at Kiona, Yakima River Basin, Washington, 1989–90. (Less-than values are graphically represented as one-half their value.)

In addition to higher concentrations of arsenic in filtered water samples from agriculturally affected parts of the basin, the load of arsenic in agricultural drains represented a large proportion of the arsenic load passing at Kiona. Sulphur Creek Wasteway, for example, had an annual streamflow representing only about 8 percent of the annual streamflow at Kiona, yet it accounted for nearly 20 percent of the filtered arsenic load at Kiona. Comparisons between loads determined from filtered water samples (an operational approximation of the dissolved load) and loads determined from arsenic in suspended sediment, showed that most of the arsenic load in the basin was in the dissolved form. For example, the annual dissolved arsenic loads in the Lower Valley at Sulphur Creek Wasteway, Grandview, and Kiona were from four to nine times higher than their respective suspended arsenic loads.

Arsenic was also present in the aquatic biota of the basin. In the curlyleaf pondweed, an aquatic plant, concentrations ranged from 0.48 to 1.5 µg/g and were threefold higher in the main stem in the Lower Valley than in the main stem in the Kittitas Valley. Concentrations of arsenic in caddisflies collected from agricultural drains in 1989 in the Lower Valley were as large as 5.4 µg/g and exceeded the 85th percentile for the basin. Asiatic clams were collected only in the Lower Valley, and arsenic concentrations varied little (3.6 to 4.6 µg/g) among Lower Valley sites. Compared to those in other studies, these concentrations were an order of magnitude higher than those reported in the Apalachicola River in Florida (Elder and Mattraw, 1984), and were at least three times higher than in the Sacra-mento River Basin of California (McCleneghan and others, 1981), but were similar to the concentrations in Asiatic clams in the San Joaquin River in California, which are considered to be affected by anthropogenic sources (Johns and Luoma, 1990; Leland and Scudder, 1990).

Exceedances of Water-Quality Guidelines

Trace element concentrations in filtered and unfiltered water samples were compared to EPA ambient water-quality criteria for the protection of aquatic life and human health, drinking water regulations, and drinking water human health advisories. Although all EPA ambient water-quality criteria are nonenforceable guidelines, they were used to screen ambient water-quality data in the Yakima River Basin in order to identify elements that may require further study by State and local health agencies. Concentrations of cadmium, chromium, copper, iron, lead, mercury, silver, and zinc in filtered and (or) unfiltered water exceeded these screening values (based on EPA's ambient water-quality criteria for the protection of aquatic organisms [U.S. Environmental Protection Agency, 1992b]) at two or more sites in the Yakima River Basin. Zinc concentrations in filtered water exceeded acute and chronic criteria for aquatic life at several sites, including those receiving irrigation return flow and those located in mountainous areas. Copper exceedances occurred during winter storm runoff periods, and coincided with seasonal historical patterns of copper exceedances attributed, in part, to the past and present use of copper sulfate (a herbicide).

The EPA ambient water-quality criteria for the protection of human health (U.S. Environmental Protection Agency, 1992b) were designed to indicate exposure of humans to a contaminant because of consumption of water and aquatic organisms, or consumption of aquatic organisms only. Concentrations of arsenic (a carcinogen) exceeded the human health screening value, determined for an increased lifetime cancer risk equivalent to 1:100,000, for the consumption of aquatic organisms and water in 43 percent of the filtered water samples and exceeded the screening value for the consumption of only aquatic organisms in 30 percent of the samples. Exceedances of arsenic were measured predominantly in the Lower Valley. Concentrations of mercury (a noncarcinogen) in filtered water samples exceeded the human health screening values for the consumption of aquatic organisms and water and consumption of only aquatic organisms in 4 percent of the samples in each case.

Trace element concentrations in filtered and unfiltered water samples were also screened by making comparisons with EPA drinking water regulations (U.S. Environmental Protection Agency, 1992c) and human health advisories (U.S. Environmental Protection Agency, 1992c; Nowell and Resek, 1994). Because filtered and unfiltered stream water samples represent untreated water, element concentrations which exceeded screening values (based on drinking water regulations[6]) do not indicate that human health was directly at risk. Concentrations of iron in unfiltered water samples exceeded the screening value in 94 percent of the samples. In filtered water samples, however, iron concentrations did meet the screening value; therefore, the exceedances in unfiltered water probably resulted from iron associated with sediment that would be removed in a water treatment process.

Unlike the ambient water-quality criteria for human health, the EPA human health advisories are based only on the consumption of domestic water. In the present study, however, ambient stream water was used to screen for health effects. Concentrations of arsenic in filtered water samples exceeded the screening value in 31 percent of the samples. The largest number of exceedances of arsenic was found in the Lower Valley. Concentrations of mercury in filtered water samples rarely exceeded the screening value.

Fish muscle, analyzed for mercury in various resident fish taxa, was collected from four sites in the Yakima River Basin in 1991 (Yakima River at Kiona, Taneum Creek at Taneum Meadow near Thorp, Yakima River at Umtanum, and Rattlesnake Creek above North Fork Rattlesnake Creek near Nile). The median mercury concentration in fish muscle from each site and for each fish species was screened for mercury concentrations that might present a potential public health concern (U.S. Environmental Protection Agency, 1994). Muscle samples collected from rainbow trout and mountain whitefish from the four sites contained mercury concentrations below the screening value for standard adults (consumers of an average of about one 6-ounce filet per month). The concentration of mercury in fish muscle exceeded the screening value for children (consumers of an average of about one 6-ounce filet per month) for all species of fish

[6] Although nearly none of the streams sampled in this study were sources for domestic water supplies, water-quality exceedances were important because many of these streams are classified by the State of Washington as Class AA or A type waters. Classes AA and A require that water "shall markedly and uniformly exceed requirements for all uses," which include domestic water supplies (Washington Administrative Code, 1992).

sampled and at all sites sampled. Similarly, screening values for recreational fishermen (consumers of about 5 6-ounce filets per month) and subsistence fishermen (consumers of about 25 6-ounce filets per month) were exceeded for all species of fish sampled and at all sites sampled.

Implications for Water Resource Monitoring and Regulation

Arsenic, cadmium, chromium, copper, lead, nickel, mercury, selenium, and zinc were found at levels of concern in the Yakima River Basin. Some of these elements in streams (for example, chromium, mercury, and nickel) are primarily from geologic sources, some (for example, lead) are primarily from anthropogenic sources, and others (for example, arsenic, copper, selenium, and zinc) are from both sources. Thus, because sources of trace elements may differ, the appropriate monitoring design strategies may differ among subbasin(s). Additionally, future monitoring might be necessary on the basis of the numerous exceedances of water-quality guidelines.

The presence of anomalously high concentrations of arsenic, lead, and zinc[7] in the streambed sediment in the Mid and Lower Yakima Valley indicates that agricultural practices, particularly those that tend to facilitate soil loss or erosion, are a source of these elements. Additionally, the presence of arsenic in filtered water samples from Sulphur Creek Wasteway (the only agricultural drain sampled) indicates that agricultural drains may act as sources of arsenic to the Lower Valley. Similarly, the presence of arsenic in Sulphur Creek Wasteway, especially higher concentrations during the nonirrigation season, indicates that shallow ground water in areas of intense irrigation may also be affected by arsenic. Efforts of future studies to delineate the effects of agricultural practices, urban runoff, and municipal sources on streambed sediment quality, at the subbasin level, may assist water-quality managers in allocating element loads to conform to sediment quality guidelines.

[7] Agricultural practices associated with orchard crops may represent a nonpoint source of zinc to streambed sediment (Fuhrer and others, 1998).

Fecal Indicator Bacteria

By Gregory J. Fuhrer and Sandra S. Embrey

The sanitary quality of river systems is a topic of great importance to water managers, recreational users, and the general public. Water from streams with poor sanitary quality can transmit diseases such as cholera, typhoid fever, and bacillary and amoebic dysentery. In July 1988, a synoptic survey of fecal indicator bacteria was performed at 58 surface-water sites in the Yakima River Basin. The month of July was selected for sampling because frequent contact with surface waters by farmers and recreationists would be expected. The results of this synoptic survey, which focused on *Escherichia coli (E. coli)*, were published by Embrey (1992) and are summarized herein. As a member of the fecal coliform group of bacteria, *E. coli* is an indicator of fecal contamination and has been correlated with the incidence of gastrointestinal disorders resulting from bodily contact with certain freshwater sources. In addition to the analyses for *E. coli*, fecal coliform bacteria also were identified so that comparisons could be made with sites sampled historically for fecal coliform bacteria. During the synoptic survey, intersite concentrations of *E. coli* and fecal coliform bacteria were similar and reflected the dominance of the *E. coli* species within the fecal coliform group of bacteria. Consequently, *E. coli* populations adequately represented populations of the fecal coliform group. Also, the *E. coli* test was less subject to interference from fungal colonies and nonfecal bacteria than the traditional fecal coliform bacteria test.

Land Use Effects

Land use was found to be an important correlative factor in the distribution of *E. coli* concentrations in the Yakima River Basin. Land use categories were assigned on the basis of the predominant land use upstream from the sampling site, to the following categories: forest, rangeland, agriculture, and agricultural drains. The agriculture and agricultural drain categories were identical in terms of land use, but differed in the intensity of use. Sites categorized as agricultural drains functioned as terminal points in the irrigation system and, thus, were expected to show the greatest effects of agriculture with respect to large concentrations of bacteria. In contrast, sites categorized as agriculture may have exhibited only transient effects resulting from agriculture. For example, a sampling site located in a canal and adjacent to land used for cattle grazing would have been placed in the agricultural land use category. The median *E. coli* concentrations increased logarithmically among the land use categories in the following order: forest < range-land < agriculture < agricultural drains (fig. 29). Additionally, significant differences existed among these categories. Concentrations of *E. coli* at the forest sites, tested with the Wilcoxon-Mann-Whitney t-test on the ranks, were significantly smaller (ρ<0.0001) than those at rangeland and agricultural sites. Similarly tested, concentrations of *E. coli* at rangeland sites were significantly smaller (ρ= 0.014) than those at agricultural sites.

The patterns of bacterial enrichment among land use categories coincided with the distribution of the reported 263,500 cattle (including calves) in the basin (Embrey, 1992). Most of these livestock were beef or nondairy cattle kept on commercial farms, finishing feedlots, or rangelands in Yakima County near the towns of Granger and Sunnyside. Yakima County contained 72 of the basin's 80 dairy farms, with 68 of these within a 12-mile radius of the town of Sunnyside. The high bacteria concentrations reported for Granger Drain and Sulphur Creek Wasteway were related to these high density livestock operations. Assuming 30,000 adult cattle and 14 gallons of waste per animal per day, dairy cattle in Yakima County alone would have generated about 420,000 gallons of waste daily (Embrey, 1992). These wastes were stored in holding ponds and later pumped onto fields as fertilizer, with occasional overflow from these ponds and runoff from the fields resulting in contamination of the nearby surface water.

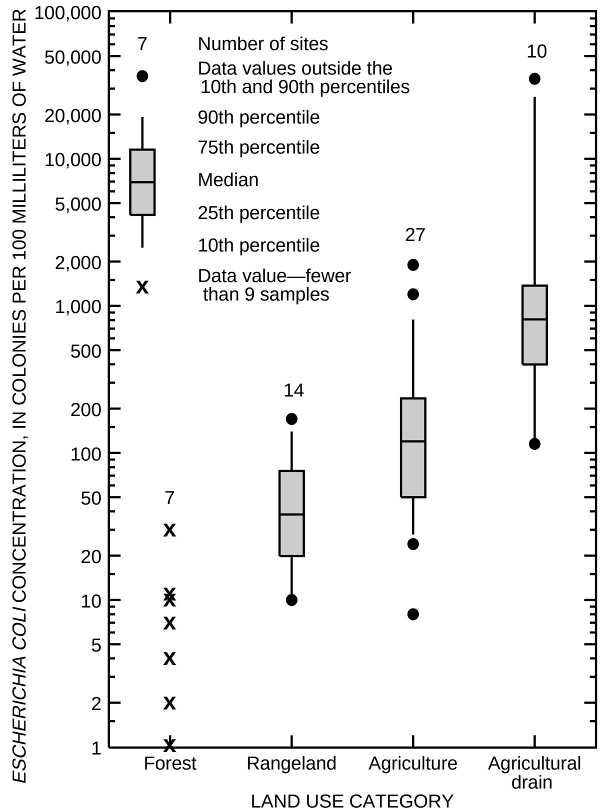


Figure 29. Statistical distribution of *Escherichia coli* concentrations grouped by forest, rangeland, agriculture, and agricultural drain land use categories, Yakima River Basin, July 1988. (To avoid statistical bias, only the median concentration for each site was statistically summarized.)

Spatial and Temporal Patterns

Concentrations of *E. coli* in the Yakima River Basin ranged from an estimated 1 to 35,000 col/100 mL (colonies per 100 milliliters) of water, with the highest concentrations measured in the canals and agricultural drains (table 25). In the Kittitas Valley, *E. coli* concentrations ranged from estimated values of 1 col/100 mL in the inflow to the Cle Elum Reservoir to 1,200 col/100 mL in Cascade Canal. In the Mid and Lower Valley, however, *E. coli* concentrations ranged from an estimated 8 col/100 mL in the Yakima River main stem at RM 70 to 35,000 col/100 mL in the Drainage Improvement District (DID) 3 Drain.

Concentrations of *E. coli* and fecal coliform bacteria at some sites varied not only spatially, but also temporally over days and even hours. These variations in concentration, which were about ±70 percent (relative to the average *E. coli* concentration), were large in comparison to the ±20 percent overall measurement error based on replicate samples and replicate split analyses. The largest variations were measured in waterways receiving irrigation return flow. At Moxee Drain,

Table 25. Concentrations of *Escherichia coli* and fecal coliform bacteria in selected water samples, Yakima River Basin, Washington, July 1988

[The median concentration is listed below if more than one sample was analyzed at a site; col/100 mL, colonies per 100 milliliters of water; E, estimated concentration based on nonideal colony count[1]; --, no data; land use assignments have been made on the basis of the predominant land use near the site]

Site name	Land use	*Escherichia coli* concentration (col/100 mL)	Fecal coliform concentration (col/100 mL)
Kittitas Valley			
Inflow to Cle Elum Reservoir	Forest	E 1	--
Yakima River at Cle Elum	Forest	E 4	E 4
Cascade Canal	Agriculture	E 1,200	--
Town Canal	Agriculture	730	--
Mid Valley			
Cherry Creek	Agriculture	460	E 150
Wilson Creek	Agriculture	340	--
Yakima River at Umtanum	Rangeland	24	24
Little Naches River at mouth	Forest	E 11	--
Tieton River at mouth	Rangeland	75	--
Moxee Drain	Agricultural drain	710	1,400
Lower Valley			
Granger Drain	Agricultural drain	1,200	1,200
Yakima River at Granger	Agriculture	440	440
Toppenish Creek near Fort Simcoe	Rangeland	E 17	--
Yakima River at river mile 70	Agriculture	E 8	--
Satus Creek downstream of Dry Creek	Rangeland	E 10	--
Drainage Improvement District (DID) 3 Drain	Agricultural drain	35,000	31,000
Sulphur Creek Wasteway	Agricultural drain	2,100	--
Yakima River at Grandview	Agriculture	150	180
Yakima River at Kiona	Agriculture	E 29	E 35
Yakima River at Van Geisen Bridge	Agriculture	24	--

[1]A nonideal colony count for fecal coliform is a count of less than 20 or greater than 60 colonies per filter (Britton and Greeson, 1987). For *Escherichia coli*, a nonideal count is a count of less than 20 or greater than 80 colonies per filter (Donna Myers, U.S. Geological Survey, Columbus, Ohio, written commun., July 1997).

for example, the *E. coli* concentration (1,300 col/100 mL) on day 1 was different, within the 95-percent confidence limits, from the mean concentration (690 col/100 mL) on day 2 (table 26). Similar differences were noted between days 3 and 4. The most notable differences, however, were measured within a single day in two samples from Sulphur Creek Wasteway. The afternoon *E. coli* measurement was 3.5 times larger than the morning measurement. This difference reflected the dynamic nature of bacteria populations in agriculturally affected waterways. The temporal variations in *E. coli* concentrations at sites relatively unaffected by agricultural return flow were small. On the basis of a limited number of temporal measurements, multiple samples over one or several days seem to be necessary to adequately characterize bacteria populations at hydrologically dynamic sites (variable flow and source of water) such as agricultural drains.

Mass Balance during the July 1988 Synoptic Sampling

The dynamics of bacterial transport were studied by computing instantaneous bacteria loads within 12 reaches of the main stem. For each reach, the load input from tributaries (tributary inflowing) was calculated. The load at the downstream site was then calculated by applying these inputs to the measured load at the upstream site. This calculated load was compared to the measured load at the downstream site, and the difference between the two was computed and expressed as a percentage of the measured load (table 27). This type of analysis is termed **mass balance**, and the closer the percentage

Table 26. Short-term variability in *Escherichia coli* (*E. coli*) concentrations, Yakima River Basin, Washington, July 1988

[95-percent (%) confidence limits were based on raw counts of *E.coli* colonies per 100 milliliters of water (col/100 mL); E, estimated concentration based on nonideal colony count[1]]

Site name	Date	Time	*E. coli* concentration ± 95% confidence limits (col/100 mL)	
Naches River at mouth	7/26/88	1330	23	± 7
	7/28/88	1800	23	± 7
	7/29/88	1510	32	± 8
Moxee Drain	7/26/88	1100	1,300	± 290
	7/27/88	0915	820	± 230
	7/27/88	1345	980	± 147
	7/27/88	1355	600	± 110
	7/27/88	1750	360	± 84
	7/28/88	1520	490	± 99
	7/29/88	0800	900	± 240
Sulphur Creek Wasteway	7/28/88	0945	900	± 240
	7/28/88	1600	3,200	± 800
Yakima River at Van Geisen Bridge	7/29/88	1050	28	± 7
	7/29/88	1300	E 19	± 15

[1]A nonideal colony count of *Escherichia coli* would be less than 20 or greater than 80 colonies per filter (Donna Myers, U.S. Geological Survey, Columbus, Ohio, written commun., July 1997).

is to zero, the better the mass balance is for the reach. Mass balance calculations also were made for conservative measures such as streamflow and dissolved solids. A positive percentage implies that unmeasured point and (or) nonpoint sources are contributing to the measured load, whereas a negative percentage implies that unaccountable losses (bacteria die-off, for example) exist in the reach. Both positive and negative losses reflect a certain amount of measurement error. In the reach between Cle Elum and Ellensburg, the measured *E. coli* load at Ellensburg differed from the calculated load by +87 percent. This positive difference probably reflects unaccounted sources of bacteria to the main stem. Because local urban development was minimal, sources in this reach were likely to be nonpoint in origin and may have included wildlife, agriculture, and recreational activity. The validity of this interpretation was further supported on the basis of the good mass balance for dissolved solids (-2 percent). Although the streamflow nearly balanced in the reach between Ellensburg and Umtanum, the mass balance for dissolved solids differed by +16 percent and for *E. coli* by -114 percent. The positive difference for dissolved solids suggests that small unaccounted sources of dissolved solids (and possibly bacteria) existed in the reach. More importantly, however, the large negative difference for *E. coli* suggests that die-off and (or) sediment deposition were the predominant factors affecting concentrations of *E. coli* in the reach. Negative mass balances for *E. coli* were measured in 9 of the 12 reaches and suggest that die-off and (or) sediment deposition were the major factors affecting *E. coli* concentrations during the summer months. Die-off and (or) sediment deposition may be important factors in the tributary sites as well.

Implications for Water Resource Monitoring and Regulation

During the synoptic survey, streamflows at most tributary sites were equivalent to historical summertime minimum discharges. Streamflows in the main stem of the Kittitas Valley, however, were larger than the historical summertime media streamflows—a condition characteristic of reser-

Table 27. Estimated mass balances for streamflow, dissolved solids, and *Escherichia coli* in the main stem, selected major tributaries, and canals, Yakima River Basin, Washington, July 26–29, 1988

[Difference, calculated subtracted from measured, expressed as the percent of measured; **bold site name**, main-stem site; ➜, tributary inflowing site; --, not applicable; E, estimate]

Site name	Yakima River mile	Streamflow (cubic feet per second)				Dissolved solids load (grams per second)				*Escherichia coli* load (millions of colonies per second)			
		Main stem				Main stem				Main stem			
		Measured	Calculated	Difference (in percent)	Tributary inflowing	Measured	Calculated	Difference (in percent)	Tributary inflowing	Measured	Calculated	Difference (in percent)	Tributary inflowing
Kittitas Valley													
Yakima River at Cle Elum	183.1	4,040	--	--	--	3,640	--	--	--	4.6	--	--	--
Yakima River at Thorp Highway Bridge at Ellensburg	165.4	3,590	--	--	--	3,170	3,230	-2	--	30.5	4.1	+87	--
➜Wilson Creek above Cherry Creek at Thrall	147.0	--	--	--	83	--	--	--	325	--	--	--	7.9
➜Cherry Creek at Thrall	147.0	--	--	--	127	--	--	--	960	--	--	--	16.5
Mid Valley													
Yakima River at Umtanum	140.4	3,760	3,800	-1	--	5,330	4,460	+16	--	25.6	55.0	-114	--
Yakima River at Harrison Road Bridge near Pomona	121.7	1,800	--	--	--	2,620	2,550	+3	--	16.8	12.3	+27	--
➜Naches River near North Yakima	116.3	--	--	--	350	--	--	--	573	--	--	--	2.3
➜Roza Power Plant Return Flow[1]	113.3	--	--	--	978	--	--	--	1,420	--	--	--	9.1
➜Wide Hollow Creek near Mouth at Union Gap	107.4	--	--	--	25.7	--	--	--	152	--	--	--	13.8
➜Moxee Drain at Thorp Road near Union Gap	107.3	--	--	--	74.1	--	--	--	409	--	--	--	21.0
Lower Valley													
Yakima River above Ahtanum Creek at Union Gap	107.3	2,940	3,230	-10	--	4,650	5,170	-11	--	39.1	63.0	-61	--
➜Ahtanum Creek at Union Gap	106.9	--	--	--	7.1	--	--	--	46	--	--	--	.2
Yakima River at river mile 91 at Zillah	91.2	163	--	--	--	414	260	+37	--	1.0	2.2	-120	--
➜East Toppenish Drain at Wilson Road near Toppenish	86.0	--	--	--	30.2	--	--	--	146	--	--	--	5.0
➜Sub-Drain Number 35 at Parton Road near Granger	83.2	--	--	--	34.2	--	--	--	158	--	--	--	1.3
➜Granger Drain at mouth near Granger	82.8	--	--	--	48.6	--	--	--	313	--	--	--	16.5
Yakima River at Highway 223 Bridge above Marion Drain at Granger	82.7	282	276	+2	--	1,380	1,030	+25	--	35.1	23.8	+32	--
➜Marion Drain at Indian Church Road at Granger	82.6	--	--	--	39.1	--	--	--	179	--	--	--	1.3
➜Toppenish Creek at Indian Church Road near Granger	80.4	--	--	--	54.1	--	--	--	261	--	--	--	1.2
Yakima River below Toppenish Creek at river mile 78.1	78.1	428	375	+12	--	1,970	1,820	+8	--	8.7	37.6	-330	--
Yakima River at river mile 72 above Satus Creek near Sunnyside	72.4	513	--	--	--	2,330	2,360	-1	--	1.2	10.4	-770	--
➜Satus Creek at gage at Satus	69.6	--	--	--	83.5	--	--	--	513	--	--	--	1.7
➜Sulphur Creek Wasteway near Sunnyside	61.0	--	--	--	159	--	--	--	1,050	--	--	--	92.3
Yakima River at Euclid Bridge at river mile 55 near Grandview	55.0	990	756	+24	--	4,870	3,890	+20	--	42.1	95.2	-130	--
Yakima River above Snipes Creek and Spring Creek near Whitstran	43.0	206	--	--	--	1,240	1,010	+18	--	2.9	9.0	-210	--
➜Spring Creek at mouth at Whitstran	41.8	--	--	--	24.2	--	--	--	127	--	--	--	1.6
➜Snipes Creek at mouth at Whitstran	41.8	--	--	--	32.9	--	--	--	102	--	--	--	1.6
➜Chandler Power Return	35.8	--	--	--	43.0	--	--	--	223	--	--	--	1.6
➜Corral Canyon Creek at mouth near Benton	33.5	--	--	--	16.5	--	--	--	351	--	--	--	.5
Yakima River at Kiona	29.9	854	323	+62	--	4,810	2,040	+58	--	7.0	8.2	-17	--
Yakima River at Van Geisan Bridge near Richland	8.4	707	--	--	--	4,020	3,980	+1	--	5.6	5.8	-4	--

[1]Values for dissolved solids and *Escherichia coli* were approximated from the values measured at the Yakima River near Pomona.

voir regulation in the basin's headwater dams. Fecal coliform concentrations measured during the synoptic survey were generally smaller than those summertime values measured historically. For example, the fecal coliform bacteria concentrations in July 1988 were generally less than the median, but greater than the minimum, concentrations measured in July, August, and September of 1972–85 (fig. 30).

Four different limits on *E. coli* concentrations are recommended by the EPA, depending on the degree of risk exposure to gastrointestinal illness from recreational contact with the water (Embrey, 1992). For water infrequently used for bathing and where incidental full body contact occurs only through an activity such as water skiing, the limit allows an *E. coli* concentration of 576 col/100 mL in a single sample (table 28). At a more stringent level, water from an area that is designated as a beach area with full body contact swimming has a suggested limit of 235 col/100 mL from a single sample. The other two limits fall between these two extremes. Surface-water samples from 11 sites exceeded all 4 of the EPA suggested limits for *E. coli* concentrations. Eight of these sites were

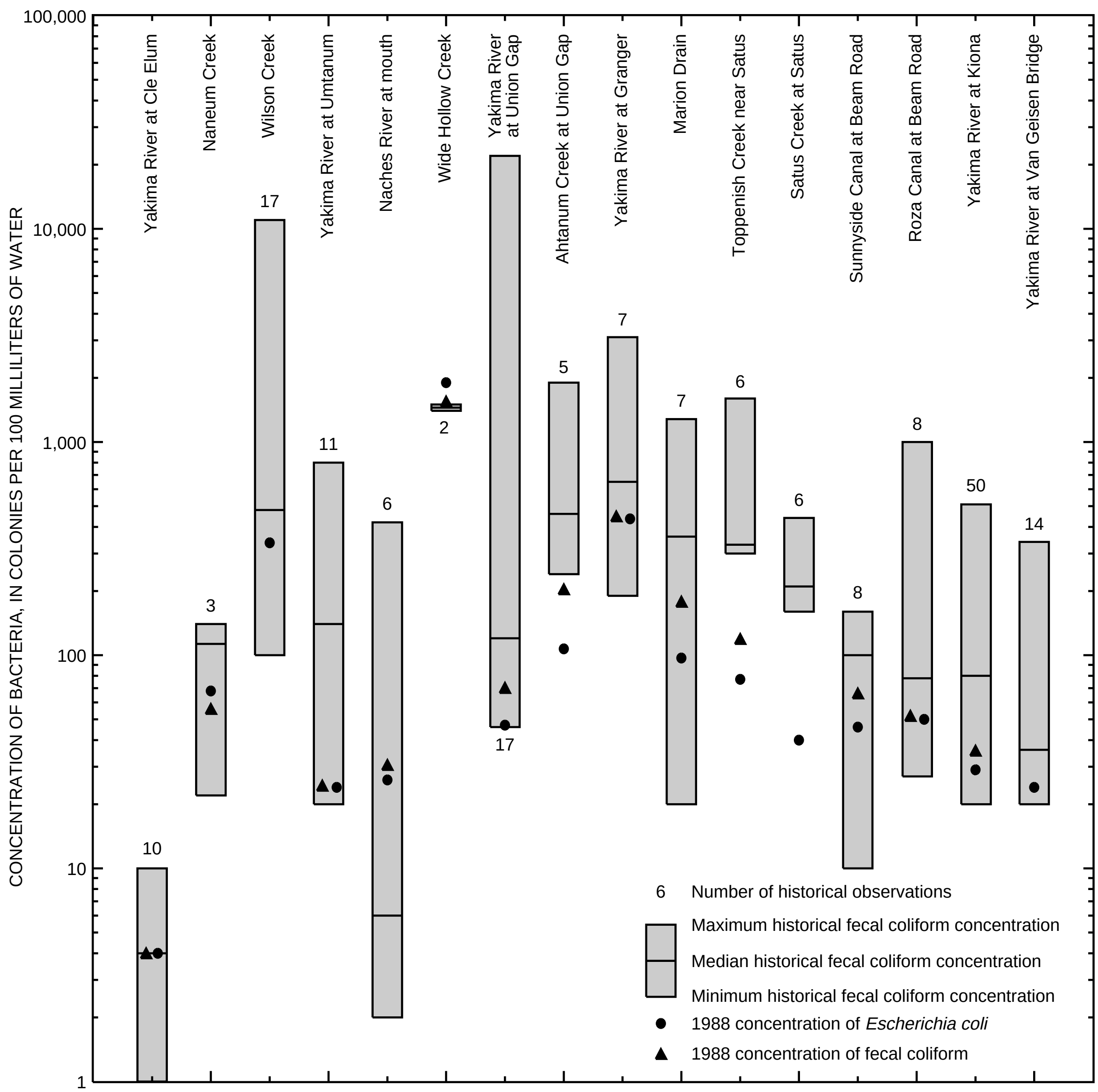


Figure 30. Comparison of historical summertime fecal coliform concentrations (1972–85) with fecal coliform and *Escherichia coli* bacteria concentrations (July 1988), Yakima River Basin, Washington.

Table 28. Sies where *Escherichia coli* concentrations exceeded U.S. Environmental Protection Agency (EPA) recommended limits for recreational contact with water and guidelines for fecal coliform concentrations based on Washington State's Class A water-quality standards

[col/100 mL; colonies per 100 milliliters of water; ✔, measured concentration exceeds the EPA limit or Washington's State standard; —, measured concentration does not exceed the EPA limit or Washington's State standard; na, not analyzed; adapted from Embrey, 1992]

Site name	EPA recommended limits for *Escherichia coli* concentrations, dependent on risk exposure from recreational contact with water: Designated beach area (235 col/100 mL)	Moderate full contact recreation (298 col/100 mL)	Lightly used contact recreation (406 col/100 mL)	Infrequent contact recreation (576 col/100 mL)	Fecal coliform concentration greater than 200 col/100 mL, based on Washington State Class A water-quality standards
Inflow to Cle Elum Reservoir	—	—	—	—	na
Yakima River at Cle Elum	—	—	—	—	—
Teanaway River	—	—	—	—	na
Yakima River at Ellensburg	—	—	—	—	na
Kittitas Main Canal	—	—	—	—	na
Cascade Canal	✔	✔	✔	✔	na
Town Canal	✔	✔	✔	✔	na
West Side Ditch	✔	✔	✔	✔	na
South Fork Manastash Creek	—	—	—	—	na
Naneum Creek	—	—	—	—	—
Wilson Creek	✔	✔	✔	—	na
Cherry Creek	✔	✔	—	—	—
Yakima River at Umtanum	—	—	—	—	—
Yakima River at Pomona	—	—	—	—	—
Little Naches River at mouth	—	—	—	—	na
Bumping River	—	—	—	—	na
Naches River at Cliffdell	—	—	—	—	na
Rattlesnake Creek at mouth	—	—	—	—	na
Tieton River at mouth	—	—	—	—	na
Naches River at Water Treatment Plant	—	—	—	—	—
Naches River at mouth	—	—	—	—	—
Wide Hollow Creek	✔	✔	✔	✔	✔
Drain near Walters Road	✔	✔	✔	✔	✔
Drain near Birchfield Road	✔	✔	✔	✔	na
Moxee Drain	✔	✔	✔	✔	✔
Yakima River at Union Gap	—	—	—	—	—
Ahtanum Creek at Union Gap	—	—	—	—	—
Yakima River at Zillah	—	—	—	—	na
East Toppenish Drain at Wilson Road	✔	✔	✔	✔	✔
Sub 35 Drain at Parton Road	—	—	—	—	na

Table 28. Sies where *Escherichia coli* concentrations exceeded U.S. Environmental Protection Agency (EPA) recommended limits for recreational contact with water and guidelines for fecal coliform concentrations based on Washington State's Class A water-quality standards—Continued

[col/100 mL; colonies per 100 milliliters of water; ✔, measured concentration exceeds the EPA limit or Washington's State standard; —, measured concentration does not exceed the EPA limit or Washington's State standard; na, not analyzed; adapted from Embrey, 1992]

Site name	EPA recommended limits for *Escherichia coli* concentrations, dependent on risk exposure from recreational contact with water				Fecal coliform concentration greater than 200 col/100 mL, based on Washington State Class A water-quality standards
	Designated beach area (235 col/100 mL)	Moderate full contact recreation (298 col/100 mL)	Lightly used contact recreation (406 col/100 mL)	Infrequent contact recreation (576 col/100 mL)	
Granger Drain	✔	✔	✔	✔	✔
Yakima River at Granger	✔	✔	✔	—	✔
Wapato Canal near terminus	—	—	—	—	na
Wanity Slough at Meyers Road	—	—	—	—	✔
Marion Drain	—	—	—	—	✔
Toppenish Creek near Fort Simcoe	—	—	—	—	na
Toppenish Creek near Satus	—	—	—	—	—
Yakima River at river mile 78	—	—	—	—	na
Yakima River at river mile 70	—	—	—	—	na
Satus Creek at Satus	—	—	—	—	na
Satus Creek downstream from Dry Creek	—	—	—	—	na
Satus Pump Canal 3	—	—	—	—	na
Drainage Improvement District 3 Drain	✔	✔	✔	✔	✔
Sulphur Creek Wasteway	✔	✔	✔	✔	na
Yakima River at Grandview	—	—	—	—	—
Sunnyside Canal at Beam Road	—	—	—	—	—
Roza Canal at Beam Road	—	—	—	—	—
Chandler Canal	—	—	—	—	—
Yakima River upstream from Spring and Snipes Creek	—	—	—	—	na
Sunnyside Canal at Gap Road	—	—	—	—	na
Roza Canal at Gap Road	—	—	—	—	—
Spring Creek near Whitstran	✔	—	—	—	na
Snipes Creek near Whitstran	—	—	—	—	na
Kennewick Canal	—	—	—	—	na
Corral Canyon Creek	—	—	—	—	na
Yakima River at Kiona	—	—	—	—	—
Yakima River at Van Geisen Bridge	—	—	—	—	na
Kennewick Canal at Route 14 and 7th Street	—	—	—	—	na

drains, ditches, or wasteways that carried agricultural return flow. The other three sites were canals, which primarily function to provide irrigation water and may or may not have carried return flow, and Wide Hollow Creek, a tributary to the main stem influenced by livestock and agricultural return flow (table 28). Although the drains are not intended for recreational use, they are accessible to people living in these agricultural areas (Embrey, 1992).

Washington State also has water-quality standards governing the suitability of water for various uses. These standards are based on median fecal coliform concentrations obtained from a monitoring program. This median concentration is not to exceed 100 col/100 mL and not more than 10 percent of the samples over a specified period are to exceed 200 col/100 mL for Class A streams (Washington Administrative Code, 1992). Most of the sites in the Yakima River Basin were on streams classified as Class A, except Sulphur Creek Wasteway which is classified as Class B. Although only single sample fecal coliform samples were analyzed as part of this study, nine sites, mostly in the southern part of the basin, had concentrations greater than 200 col/100 mL (table 28).

Radionuclides

By Ted R. Pogue, Jr.

Gross alpha and gross beta activity in filtered water and suspended sediment were measured at seven fixed site locations in the surface waters of the Yakima River Basin during the 1987–91 WY (table 29). Natural uranium (U) alpha activity and strontium (Sr) plus yttrium (Y-90) and cesium (Cs-137) beta activity were used as standards to quantify measured activities in units of concentration. On the basis of the Washington Administrative Code (1992), all of the fixed sites were on Class A streams except Sulphur Creek Wasteway near Sunnyside (RM 61), which was a Class B stream.

Gross alpha measurements for the Yakima River Basin, when compared with the maximum contaminant level (MCL) of 15 pCi/L (picocuries per liter) for gross alpha activity established by the National Primary Drinking Water Regulations (U.S. Environmental Protection Agency, 1991), excluding uranium and radon, revealed no exceedances. In order to compare gross alpha measurements from the Yakima River Basin to the MCL, the measurements from the Yakima River Basin were converted to picocuries per liter. The conversion factor of 0.678 pCi/μg is based on the assumptions that uranium was the only alpha emitter, U-235 was absent, and secular equilibrium between U-234 and U-238 existed. The validity of these assumptions for the gross alpha measurements in the Yakima River Basin is uncertain. The proposed MCL for gross beta activity of 20 pCi/L for radon (Ra-228) (U.S. Environmental Protection Agency, 1991) was not exceeded in the Yakima River during the 1987–91 WY.

Median gross alpha activities in filtered water and suspended sediment for the fixed sites in the Yakima River Basin were <0.5 and <0.4 μg/L as U, respectively (table 29). These observed activities were similar to median activities for the Snake River at Burbank, Washington (2.6 and <0.6 μg/L as U, respectively), a USGS NASQAN site located 11 miles from the Yakima River confluence near Columbia River mile 324. Similarly, median gross beta measurements in filtered water and suspended sediment compared closely to median values for the Snake River. Localized contamination in the Yakima River Basin during the 1987–91 WY is, therefore, unlikely.

Ecological Assessment

By Thomas F. Cuffney, Michael R. Meador, Stephen D. Porter, *and* Martin E. Gurtz

Biological investigations in the Yakima River Basin indicated linkages between biological characteristics of streams and rivers and land uses that influence water quality. These investigations also clarified relations among the physical, chemical, and biological characteristics of these streams, which can lead to development of improved strategies for the wise use and management of surface-water resources in the Yakima River Basin. Investigations conducted as part of the NAWQA pilot studies also helped to form a basis for decisions on sampling design and field methods for NAWQA. The following is a summary of information con-

Table 29. Gross alpha and gross beta activities in filtered water and suspended sediment in the Yakima River Basin (1987–91 water years) and the Snake River at Burbank (1974–92 water years), Washington

[The activities listed for the Snake River at Burbank (station number 13353200) are median values calculated from data in the National Water Inventory System (NWIS) data base; µg/L = micrograms per liter; pCi/L = picocuries per liter; for gross alpha, 1 µg = 0.678 pCi]

		Gross alpha activity (µg/L)		Gross alpha activity (pCi/L)		Gross beta activity, as Sr plus Y-90 (pCi/L)		Gross beta activity, as Cs-137 (pCi/L)	
Site name	Date	Filtered water	Suspended sediment	Filtered water	Suspended sediment	Filtered water	Suspended sediment	Filtered water	Suspended sediment
Cle Elum	04–30–87	<0.4	<0.4	<0.3	<0.3	<0.4	<0.4	<0.4	<0.4
	08–10–87	<.4	<.4	<.3	<.3	<.4	<.4	<.4	<.4
	01–10–90	<.6	2.5	<.4	1.7	<.6	1.2	<.6	1.5
Umtanum	05–01–87	<.4	<.4	<.3	<.3	1.1	.8	1.3	.9
	08–18–87	<.4	<.4	<.3	<.3	.5	<.4	.6	<.4
	12–05–89	<.6	<.6	<.4	<.4	<.6	.9	.6	1.1
Naches	04–30–87	<.4	1.8	<.3	1.2	.5	1.1	.6	1.2
	08–10–87	<.4	<.4	<.3	<.3	1.2	<.4	1.4	<.4
Union Gap	05–01–87	<.4	2.4	<.3	1.6	.6	1.2	.6	1.3
	08–11–87	<.4	<.4	<.3	<.3	.9	<.4	1.0	<.4
	12–05–89	<.6	1.3	<.4	.9	.9	2.1	1.1	2.6
Sulphur Creek	05–01–87	3.3	6.8	2.2	4.6	2.5	3.0	3.6	3.5
	08–18–87	5.5	.5	3.7	.3	3.4	.6	4.6	.6
	11–17–87	15	<.4	10	<.3	7.7	1.5	11	1.5
Grandview	05–02–87	<.4	<.4	<.3	<.3	.7	.9	.8	.9
	11–18–87	1.8	<.4	1.2	<.3	2.6	1.1	3.4	1.2
	12–06–89	<.6	3.9	<.4	2.6	1.5	3.7	1.9	4.7
Kiona	11–19–87	1.3	<.4	.9	<.3	2.4	<.4	3.2	<.4
	12–06–89	.7	.9	.5	.6	1.4	1.3	1.7	1.6
	05–02–87	<.4	<.4	<.3	<.3	1.1	<.4	1.3	<.4
Snake River at Burbank	1974–92	2.6	<.6	2.0	.7	2.8	.7	3.2	.7

tained in a report about the ecology of the Yakima River Basin by Cuffney and others (1997).

Development in the Yakima River Basin has had severe effects on biological resources. For example, anadromous fish runs declined from more than 500,000 adults annually during the 1880s to less than 4,000 adults during the 1980s (Bonneville Power Administration, 1988). Habitat loss, dams, and poor water-quality conditions are the major factors thought to be responsible for the decline of the anadromous fishery in the basin. The presence and accumulation of agricultural chemicals in fish tissue, particularly pesticides such as DDT, are important water-quality and human health issues in the lower Yakima River (Rinella, McKenzie, Crawford, and others, 1992; Rinella and others, 1993). The effects of agriculture (for example, increased concentrations of nutrients and pesticides and habitat destruction) on aquatic biota are not well documented for benthic invertebrates, algae, and nongame species of fish.

Effective management of surface-water resources in the Yakima River Basin requires the coupling of site status, derived by ranking physical, chemical, and biological conditions at impaired sites against reference sites (Ohio Environmental Protection Agency, 1987; Plafkin and others, 1989), with an understanding of how land use changes physical and chemical site characteristics and how biota respond to these changes. Site status and an understanding of the factors that control water quality allow managers to identify sites that require attention and modify factors known to control water quality.

Assessment of biological communities complements the assessment of chemical conditions by (1) providing a direct measurement of water-quality effects, (2) integrating responses to a variety of environmental exposure pathways, (3) incorporating secondary effects that arise from actions of populations through competitive and predator-prey interactions, and (4) providing the only approach to water-quality assessment that is sensitive to both toxicological influences and habitat impairment resulting from changes in land and water use. The integration of physical, chemical, and biological indicators of water-quality conditions reflects the primary objective of the National Clean Water Act, as amended by the Water Quality Act of 1987 (U.S. Government Printing Office, 1988)—to “restore and maintain chemical, physical, and biological integrity of the nation’s waters.”

Study Design and Methods

The Yakima River Basin is composed of three natural divisions or ecoregions: Cascades, Eastern Cascades Slopes and Foothills (Eastern Cascades), and Columbia Basin (Omernik, 1987). Each of these ecoregions represents a unique combination of landscape features that produce a distinctive terrestrial vegetation and climate. Large-river sites in each ecoregion were combined into a separate large-river group because fish, benthic invertebrate, and algal communities of large rivers are known to differ substantially from those of smaller streams (Vannote and others, 1980). This approach provided four natural ecological divisions in which to investigate natural and human effects on water quality and biological communities. Dominant land uses (forestry, agriculture, and urban) were used to depict human-related factors that modify physical, chemical, and biological conditions within these natural divisions.

Within the three ecoregions, ecological sampling was conducted at 6 sites in the Cascades ecoregion, 5 sites in the Eastern Cascades ecoregion, and 14 sites in the Columbia Basin ecoregion (table 30). Seven of the Columbia Basin sites (Yakima River at Umtanum, Naches River at North Yakima, Yakima River above Ahtanum Creek, Yakima River at Parker, Yakima River below Toppenish, Yakima River at RM 72, and Yakima River at Kiona) and one of the Cascades sites (Yakima River at Cle Elum) formed the large-river site group. These sites constituted a subset of the sites sampled to characterize chemical conditions in the basin.

A combination of qualitative and quantitative methods was used to collect representative samples of fish, benthic invertebrate, and algal communities (Cuffney and others, 1997). Fish were collected at 22 of the 25 ecological sampling sites, using backpack electrofishing at wadeable sites (17 sites) and boat electrofishing at nonwadeable sites (5 sites), following the procedures of Meador, Cuffney, and Gurtz (1993). Quantitative samples of benthic invertebrates were collected using a 0.25-square meter Slack sampler, and qualitative samples were collected from all accessible instream habitats and composited to form a single qualitative multihabitat (QMH) sample. QMH samples provide a comprehensive estimate of the variety of taxa present at each site but not their abundance (Cuffney and others, 1993). Quantitative samples of benthic algae (periphyton) were collected from submerged rocks using the NAWQA SG-92 periphyton sampling protocol (Porter and others, 1993). In contrast with invertebrate sampling, QMH algal samples were not collected during this study; therefore, taxa richness at a site (number of different organisms collected) could not be estimated because only one microhabitat in the stream reach was sampled. More than 140 variables were measured and used to describe the physical, hydrologic, land use, habitat, and chemical characteristics of each site. Site characterization was based on a tiered design that incorporated information at basin, stream segment, stream reach, and site levels (Meador, Hupp, and others, 1993; Cuffney and others, 1997).

Indices were developed to characterize the relative magnitude of metals contamination, nonpesticide agricultural intensity (NPAI), and pesticide contamination in filtered water, suspended sediment, and bed sediment (Cuffney and others, 1997). These indices represent multiples of the background (minimum) concentrations. The metals index was restricted to metals typically associated with human activities (copper, chromium, mercury,

Table 30. Sites and communities sampled for biology, habitat, and chemistry, Yakima River Basin, Washington, 1990
[Abbreviated site names for fixed sites are shown in parentheses; NF, North Fork; X, sampled; —, not sampled; S, sampling suspended due to the presence of spawning salmon]

Site name	Station number	Ecological site abbreviation	Community sampled		
			Fish	Benthic invertebrates	Algae
Cascades Ecoregion					
Cooper River at Salmon LaSac near Roslyn[1]	12478200	COOPER	—	—	—
NF Teanaway River below bridge at Dickey Creek Campground	12479750	NFTEA	—	X	X
Taneum Creek at Taneum Meadow near Thorp	12481900	TANEUM	X	X	X
Naneum Creek below High Creek near Ellensburg	12483750	NANEUM	X	X	X
American River at Hells Crossing near Nile	12488250	ARHC	X	X	X
NF Little Naches River above Middle Fork near Cliffdell	12497200	NFLNAC	—	X	X
Eastern Cascades Ecoregion					
South Fork Manastash Creek near Ellensburg	12483190	SFMAN	X	X	X
Little Naches River at mouth near Cliffdell	12487200	LNCL	X	X	X
Rattlesnake Creek above NF Rattlesnake Creek near Nile	12489100	RATSNK	X	X	X
South Fork Ahtanum Creek above Tampico	12500900	SFAHTAN	X	X	X
Satus Creek above Wilson Charley Canyon near Toppenish	12507594	SATTOP	X	X	X
Columbia Basin Ecoregion					
Cherry Creek above Whipple Wasteway at Thrall	12484440	CHERRY	X	X	X
Umtanum Creek near mouth at Umtanum	12484550	UMTAN	X	X	X
Moxee Drain at Thorp Road near Union Gap	12500430	MOXEE	X	X	X
Wide Hollow Creek at old sewage treatment plant at Union Gap	12500442	WIDE	X	X	X
Ahtanum Creek at Union Gap	12502500	AHTAN	X	X	X
Granger Drain at mouth at Granger	12505460	GRANG	X	X	X
Satus Creek below Dry Creek near Toppenish	12508500	SATUSBDC	X	X	X
Satus Creek at gage at Satus	12508620	SATUSG	X	X	X
Spring Creek at mouth at Whitstran	12509710	SPRING	S	X	X
Large-river Sites					
Yakima River at Cle Elum (Cle Elum)	12479500	YRCE	X	X	X
Yakima River at Umtanum (Umtanum)	12484500	YRUM	X	X	X
Naches River near North Yakima (Naches)	12499000	NACNY	—	X	X
Yakima River above Ahtanum Creek at Union Gap[1] (Union Gap)	12500450	YRAHTAN	—	—	—
Yakima River at Parker	12503950	YRPARK	X	X	X
Yakima River below Toppenish Creek near Satus	12507525	YRTOP	X	X	X
Yakima River at river mile 72[1]	12507585	YRRM72	—	—	—
Yakima River at Kiona (Kiona)	12510500	YRKIONA	X	X	X

[1]Biological communities were not sampled at Cooper River, Yakima River above Ahtanum Creek at Union Gap, and Yakima River at river mile 72. These sites were used to represent the concentrations of pesticides in filtered water and suspended sediment at sites in the Cascades and Eastern Cascades ecoregions (Cooper River), Yakima River at Parker (Yakima River above Ahtanum Creek), and Yakima River at Toppenish Creek (Yakima River at river mile 72).

nickel, zinc, and lead in bed sediment). The NPAI index included turbidity, conductivity, substrate embeddedness, and nutrients (total nitrogen, filtered ammonia, unfiltered ammonia plus organic nitrogen, filtered nitrite plus nitrate, total phosphorus, and SRP). Separate indices were calculated for pesticides in filtered water (52 constituents), suspended sediment (23 constituents), and bed sediment (13 constituents). An index of pesticides in fish tissue was calculated for each site by using the mean concentrations of pesticides measured in several species of fish; each tissue sample consisted of a composite of several individuals of a single species (Rinella, McKenzie, Crawford, and others, 1992). The disturbance index was calculated for each site by averaging the five indices (metals, NPAI, and pesticides in filtered water, suspended sediment, and fish tissue) and then dividing the average for each site by the maximum average observed over all sites; this approach gave equal weighting to each of the five indices (Cuffney and others, 1997).

Fish

Previous biological investigations in the Yakima River Basin emphasized salmonids and other species of sport fish, and the physical factors (flow, temperature) that affected their abundance and survival. In this investigation, fish community composition was consistent with the fish fauna of similar river systems in the Pacific Northwest, composed primarily of salmonids and sculpins in the headwaters with more species present as the gradient decreases and water temperature and stream size increase. The most common of the 33 fish taxa collected were speckled dace, rainbow trout, and Paiute sculpin; the number of taxa per site ranged from 3 to 18. In the Cascades and Eastern Cascades ecoregions, the families Salmonidae and Cottidae (sculpins) dominated the cool water fish community. The rest of the basin was a warm water fishery dominated by catostomids (suckers) and nonnative species such as centrarchids (sunfish and bass). Fish community composition proved to be useful in distinguishing biological differences among sites within the Columbia Basin and large-river site groups.

Thirty-three fish taxa (5,854 individuals) were collected from 21 sites (table 31); 22 species are considered native species. Speckled dace was the most abundant species collected, accounting for 27 percent of the total number of fish collected. Rainbow trout and Paiute sculpin accounted for 12 and 10 percent of the total, respectively. Torrent sculpin, redside shiner, largescale sucker, and northern squawfish also were abundant, each accounting for greater than 5 percent of the total number of fish collected. Taxon richness ranged from 3 at Yakima River at Cle Elum and South Fork Ahtanum Creek to 18 at Cherry Creek. The number of fish collected at each site ranged from 65 at Yakima River at Kiona to 1,492 at Satus Creek below Dry Creek.

Fish community structure in the Yakima River Basin can be classified into three broad categories: (1) communities of relatively higher elevation, lower water temperature tributary sites; (2) communities of lower elevation, warmer water temperature, tributary sites; and (3) communities of main stem river sites. In general, cold water streams rarely exceed 25°C (degrees Celsius) and typically contain salmonids and sculpins, whereas warm water streams often exceed 25°C and are characterized by a more diverse fish fauna, including centrarchids (sunfish and bass), cyprinids (minnows and carp), and catostomids (suckers). This pattern was typical of the distribution of fish species observed in the Yakima River Basin and was consistent with expected patterns in fish community structure for Pacific Northwest streams (Patten and others, 1970; Li and others, 1987).

Invertebrates

Among the three biological groups studied, the highest number of taxa (193) was found among the invertebrates; 67 percent of these taxa occurred in the Cascades and (or) Eastern Cascades ecoregions, 64 percent in the Columbia Basin, and 49 percent in the large-river site groups (for a list of taxa, see Cuffney and others, 1997). Insects, particularly sensitive forms such as mayflies, stoneflies, and caddisflies (Ephemeroptera, Plecoptera, and Trichoptera—EPT fauna), formed the majority of the invertebrate communities of the Cascades and Eastern Cascades and were useful in discriminating

Table 31. Common and scientific names, tolerance, trophic group, and native or introduced status of fish collected, Yakima River Basin, Washington, 1990

[Data are from Hughes and Gammon (1987) and Chandler and others (1993); tolerant species are adaptable to environmental degradation resulting from erosion and siltation, organic and inorganic pollution, channelization, and flow fluctuations (Bramblett and Fausch, 1991); intolerant species are the converse of tolerant and are the first species to decline when streams are degraded by human activity (Karr and others, 1986); trophic group is based on the diet of adult fish (after Karr and others, 1986): F, filter feeder; I, invertivore (greater than [>] 90 percent [%] invertebrates); O, omnivore (25-90% plant-detritus, 10-75% invertebrates); H, herbivore (>90% plant-detritus, <10% invertebrates); and P, piscivore (>90% fish); —, not determined]

Common name	Scientific name	Tolerance	Trophic group	Native or introduced
Lampreys	Petromyzontidae			
River lamprey	*Lampetra ayresi*	Intolerant	F	Native
Western brook lamprey	*Lampetra richardsoni*	Intolerant	F	Native
Unidentified lamprey	*Lampetra* sp.	—	—	—
Minnows and carps	Cyprinidae			
Chiselmouth	*Acrocheilus alutaceus*	Tolerant	H	Native
Common carp	*Cyprinus carpio*	Tolerant	O	Introduced
Northern squawfish	*Ptychocheilus oregonsis*	Tolerant	P	Native
Longnose dace	*Rhinichthys cataractae*	Tolerant	I	Native
Leopard dace	*Rhinichthys falcatus*	Tolerant	I	Native
Speckled dace	*Rhinichthys osculus*	Tolerant	I	Native
Unidentified dace	*Rhinichthys* sp.	—	—	—
Redside shiner	*Richardsonius balteatus*	Tolerant	I	Native
Unidentified minnow	Cyprinidae	—	—	—
Suckers	Catostomidae			
Bridgelip sucker	*Catostomus columbianus*	Tolerant	H	Native
Largescale sucker	*Catostomus macrocheilus*	Tolerant	O	Native
Mountain sucker	*Catostomus platyrhynchus*	Tolerant	H	Native
Salmon and trouts	Salmonidae			
Coho salmon	*Oncorhynchus kisutch*	Intolerant	I	Native
Chinook salmon	*Oncorhynchus tshawytscha*	Intolerant	I	Native
Cutthroat trout	*Oncorhynchus clarki*	Intolerant	I	Native
Rainbow trout	*Oncorhynchus mykiss*	Intolerant	I	Native
Mountain whitefish	*Prosopium williamsoni*	Intolerant	I	Native
Brown trout	*Salmo trutta*	Intolerant	I	Introduced
Brook trout	*Salvelinus fontinalis*	Intolerant	I	Introduced
Dolly Varden	*Salvelinus malma*	Intolerant	P	Native
Sticklebacks	Gasterosteidae			
Three-spine stickleback	*Gasterosteus aculeatus*	Intolerant	I	Native
Sculpins	Cottidae			
Paiute sculpin	*Cottus beldingi*	Intolerant	I	Native
Slimy sculpin	*Cottus cognatus*	Intolerant	I	Native
Shorthead sculpin	*Cottus confusus*	Intolerant	I	Native
Torrent sculpin	*Cottus rhotheus*	Intolerant	I	Native
Sunfishes	Centrarchidae			
Pumpkinseed	*Lepomis gibbosus*	Intolerant	I	Introduced
Bluegill	*Lepomis macrochirus*	Tolerant	I	Introduced
Unidentified sunfish	*Lepomis* spp.	—	—	—
Smallmouth bass	*Micropterus dolomieu*	Intolerant	P	Introduced
Largemouth bass	*Micropterus salmoides*	Intolerant	P	Introduced

among sites within site groups. Total and EPT taxon richness tended to be lower in the Columbia Basin and large-river site groups, though insects still dominated the community richness and abundance.

Many of these differences were associated with changes in elevation and land use. Elevation affects the distribution of many invertebrate taxa by influencing other physical and biological factors (for example, temperature, riparian conditions, and the quality and quantity of food). The influence of elevation was evident in the distribution of stoneflies, which showed a strong positive relation between elevation and richness and were largely confined to higher elevation streams in the Cascades and Eastern Cascades site group. Invertebrate taxon richness was directly related to the intensity of agriculture and the degree of canopy closure, two factors that represent the degree to which a site has been disturbed and its elevation. The types and numbers of taxa collected from the Cascades, Eastern Cascades, and Columbia Basin ecoregions were similar to those collected during other studies conducted in this area, despite differences in collection methods and levels of identification (Plotnikoff, 1995; Carter and others, 1996).

Algae

Algae were represented by a total of 134 epilithic[8] taxa (26 to 76 per site) and communities were dominated by diatoms throughout the basin (for a list of taxa, see Cuffney and others, 1997). Autecological[9] classifications or guilds were based on published literature (Lowe, 1974; Fairchild and others, 1985; Van Dam and others, 1994) and included: **cosmopolitan**—widely distributed species tolerant of a large range of environmental conditions; **eutrophic**—species tolerant of high nutrient concentrations; **halophilic**— species that prefer sites with high dissolved solids; **nitrogen fixers**—species capable of fixing nitrogen and commonly found in nitrogen-poor waters; **facultative nitrogen heterotrophs**—species capable of using reduced nitrogenous compounds as an energy source; **oligotrophic** and **oligothermal**— species that prefer sites with low nutrient concentrations and low temperatures; and **siltation tolerant**—species capable of surviving in areas with high siltation rates.

Nitrogen-fixing forms were common in the low nutrient streams of the Cascades and Eastern Cascades, whereas eutrophic forms were common in the high nutrient streams of the Columbia Basin. Algal taxon richness and abundance were not related to biomass (chlorophyll *a* and *b*), ecoregion, site group, or agricultural intensity. The relative abundances of autecological guilds were, however, significantly correlated with indicators of agricultural intensity, particularly with nutrient concentrations. Sites in the Satus Creek drainage had unusually high densities of algae (>3,300,000 cells per square centimeter).

Diatoms constituted 77 to 97 percent of the taxa encountered at all sites, while green algae constituted less than 8 percent. Algal communities were composed primarily (>50 percent of total abundance) of diatoms (17 sites) or *Nostoc* (6 sites) at all sites except Satus Creek below Dry Creek and Taneum Creek, which were dominated by *Oscillatoria* (80 percent) and *Microcystis* (73 percent), respectively. Algal community composition based on autecological guilds revealed that communities were dominated by nitrogen fixers, facultative nitrogen-heterotrophs, eutrophic, halophilic, and cosmopolitan algae. Cosmopolitan taxa were the most abundant autecological group at six sites (American River at Hells Crossing, North Fork Little Naches River, South Fork Ahtanum Creek, Spring Creek, Yakima River at Cle Elum, and Naches River at North Yakima). Cosmopolitan algae are widely distributed because, unlike other autecological guilds, they tolerate a wide range of environmental conditions. Therefore, the abundance of cosmopolitan taxa is not indicative of any specific water-quality condition. By contrast, nitrogen-fixing algae tend to thrive even when nitrogen concentrations are low because they can use atmospheric nitrogen. Nitrogen-fixing algae were found in abundance at six sites in the Cascades and Eastern Cascades site group, one site in the Columbia Basin site group, and no sites in the large-river site group. Facultative nitrogen-heterotrophs are indicative of high nitrogen concentrations

[8] Epilithic—growing on stones.

[9] Autecological—referring to the branch of ecology dealing with the individual organism and its environment.

because they are capable of using reduced nitrogenous compounds, in addition to photosynthesis, as an energy source (Cholnoky, 1958; 1968; Schoeman, 1973; Lowe, 1974). Nitrogen heterotrophs and halophils, which constituted only a minor proportion of abundance (<10 percent) in the Cascades and Eastern Cascades site groups, were often a major component (>20 percent) of algal communities in the Columbia Basin and large-river site groups in conjunction with eutrophic algae.

Indices of Physical and Chemical Conditions

Physical and chemical site conditions were summarized using indices of metals enrichment, agricultural intensity, pesticide contamination, and disturbance (table 32) that classified site conditions as high, moderate, or low impairment (Cuffney and others, 1997). The metals index indicated that metal enrichment was generally low (<4) throughout the basin with the exception of Yakima River at Cle Elum, North Fork Teanaway River, Taneum Creek, South Fork Manastash Creek, and Wide Hollow Creek. With the exception of Wide Hollow Creek, elevated levels of chromium, mercury, lead, and nickel probably originated from geologic formations within the upper Yakima River Valley (Fuhrer, McKenzie, and others, 1994; Fuhrer, Fluter, and others, 1994; Leland, 1995). Wide Hollow Creek, which drains urban and agricultural areas, showed enrichment in mercury, lead, and zinc that is probably associated with land use rather than with upstream geologic sources.

Agricultural intensity, as measured by the NPAI index (table 32), indicated that agriculture was largely confined to the Columbia Basin site group and varied widely in intensity among these sites. Moxee Drain, Granger Drain, and Spring Creek were affected by high levels of agricultural intensity (>100). Total nitrogen was the dominant variable in the NPAI index. In general, the three pesticide indices were significantly correlated with the NPAI index of agricultural intensity, indicating the close connection between the use of fertilizers and pesticides in the Yakima River Basin. Pesticide concentrations in the Cascades, Eastern Cascades, and at Satus Creek below Dry Creek were probably near background levels. The disturbance index indicated that disturbance in the Cascades and Eastern Cascades ecoregion was low (<2.0). This index emphasizes agricultural effects and is strongly correlated with the NPAI index and the pesticide indices. Silvicultural effects are known to vary among the heavily forested Cascades and Eastern Cascades sites but probably are not well represented by the disturbance index. Therefore, the actual disturbance patterns in the Cascades and Eastern Cascades ecoregions may have been substantially different from what is depicted in this report. In this regard, biological indicators of site condition may be preferable to physical and chemical indicators, because biological indicators respond to a broader range of water-quality degradation.

Condition of Biological Communities

Multimetric community condition indices indicated substantial differences in the level of biological impairment within each of three site groups (Cascades and Eastern Cascades [combined], Columbia Basin, and large rivers). Dividing the Yakima River Basin into these groups (derived from ordination analyses of community and physical and chemical data) minimized the complicating effects that climate and elevation have on the distribution of organisms. The multimetric community condition indices, when used in conjunction with community ordinations, enabled the separation of biological effects associated with the major natural environmental gradients in the basin (elevation, stream size) from those related to human activities. This separation was accomplished by determining site conditions separately for each of the three site groups by using reference sites specific to each site group. In this manner, the effects of variables such as elevation and stream size could be separated from variables of primary interest, such as land use, so that the impact of human activities in the basin could be examined.

The combination of multivariate and multimetric approaches produced an understanding of water quality in the basin not possible with either method alone. Fish, invertebrate, and algal communities often gave somewhat different but complementary indications of site impairment because the effects of water-quality degradation were influenced by dif-

Table 32. Summary of site conditions determined from indices that characterize metals enrichment, agricultural intensity (NPAI index), pesticide contamination, and disturbance, Yakima River Basin, Washington, 1990

[See table 30 for full site names; abbreviated site names for fixed sites are shown in parentheses; thresholds for high (dark shading) levels of metals, agricultural intensity, pesticides in filtered water, pesticides in suspended sediment, pesticides in fish tissues, and disturbance indices are: greater than (>) 20, >100, >30, >100, >20, and >20, respectively; corresponding thresholds for low (light shading) levels are: less than (<) 4, <12, <6, <10, <10, and <4, respectively; conditions were assigned to the moderate (medium shading) level if they did not fall in either the high or low category; missing values precluded the determination of site conditions based on pesticides in bed sediment (no shading); —, data could not be estimated]

		Site condition indices						
				Index of pesticide concentrations in				
Station number	Shortened site name	Metals index	NPAI index	Filtered water	Suspended sediment	Bed sediment	Fish tissue	Disturbance index
	Cascades site group							
12479750	North Fork Teanaway	**9.6**	2.6	[1]3.0	[1]4.0	4.2	0.1	1.6
12481900	Taneum Creek near Thorp	**5.4**	2.8	[1]3.0	[1]4.0	4.4	0.1	1.2
12483750	Naneum Creek near Ellensburg	2.3	6.4	[1]3.0	[1]4.0	4.5	0.1	1.3
12488250	American River at Hells Crossing	3.5	4.3	[1]3.0	[1]4.0	1.8	0.1	1.2
12497200	North Fork Little Naches River	2.2	3.0	[1]3.0	[1]4.0	—	[2]0.1	1.0
	Eastern Cascades site group							
12483190	South Fork Manastash Creek	**4.0**	8.7	[1]3.0	[1]4.0	4.6	0.1	1.6
12487200	Little Naches River at mouth	2.5	7.1	[1]3.0	[1]4.0	4.2	0.4	1.4
12489100	Rattlesnake Creek near Nile	2.9	4.0	[1]3.0	[1]4.0	1.0	0.1	1.1
12500900	South Fork Ahtanum Creek	1.4	11.4	[1]3.0	[1]4.0	5.4	[2]0.1	1.6
12507594	Satus Creek near Toppenish	2.8	9.0	1.3	3.7	—	0.2	1.4
	Columbia Basin site group							
12484440	Cherry Creek at Thrall	2.0	**70.7**	**19.0**	**88.8**	147.2	1.9	**14.8**
12484550	Umtanum Creek near mouth	2.2	9.4	1.6	4.9	1.2	1.3	1.6
12500430	Moxee Drain near Union Gap	1.7	108.1	58.7	138.1	105.2	**16.4**	26.3
12500442	Wide Hollow Creek at Union Gap	**4.8**	**79.0**	**11.0**	**20.6**	26.4	**13.1**	**10.5**
12502500	Ahtanum Creek at Union Gap	2.4	**60.6**	**6.2**	**15.8**	—	6.0	**7.4**
12505460	Granger Drain at mouth at Granger	2.2	200.0	41.2	504.6	89.7	36.5	63.8
12508500	Satus Creek below Dry Creek	1.7	8.7	[1]3.0	[1]4.0	5.0	0.4	1.4
12508620	Satus Creek at gage at Satus	2.6	**72.5**	**22.1**	**30.6**	—	2.4	**10.6**
12509710	Spring Creek at mouth near Whitstran	2.2	144.4	**18.2**	304.8	—	7.7	38.8
	Large river site group							
12495000	Yakima River at Cle Elum (Cle Elum)	**6.2**	3.4	1.4	8.0	—	1.7	1.7
12484500	Yakima River at Umtanum (Umtanum)	2.9	**16.2**	5.8	7.7	7.6	4.8	3.0
12499000	Naches River near North Yakima (Naches)	3.2	6.8	1.5	1.7	—	**12.7**	2.1
12503950	Yakima River at Parker	3.2	**27.5**	[3]**7.2**	[3]9.8	[3]89.2	21.9	**5.7**
12507525	Yakima River below Toppenish Creek	2.9	**50.5**	[4]**12.5**	[4]**50.4**	—	24.9	**11.5**
12510500	Yakima River at Kiona (Kiona)	2.8	**48.0**	**17.2**	**49.3**	15.3	27.8	**11.8**

[1]Estimated from data collected at Cooper River at Salmon LaSac near Roslyn, Washington.
[2]Estimated from concentrations measured at Cascade and Eastern Cascade sites.
[3]Estimated from data collected at Yakima River above Ahtanum Creek at Union Gap.
[4]Estimated from data collected at Yakima River at river mile 72.

ferences in the life spans of the organisms (years for fish, months for invertebrates, and weeks for algae), their mobility (fish are highly mobile, invertebrates and algae are relatively immobile), and their physiology. The environmental optima for each taxon revealed that the biota were divided into three community types: (1) a higher elevation, cold water, low agricultural-intensity community, (2) a lower elevation, warm water, low agriculture community, and (3) a lower elevation, warm water, moderate to high agricultural-intensity community.

Fish

The multimetric approach taken to characterize the condition of fish communities was limited to four metrics that are a subset of those used in most versions of the Index of Biotic Integrity (Karr and others, 1986). These metrics (table 31) characterized tolerance, trophic association, origin (native or introduced), and health of each fish species, and were based on classifications of Hughes and Gammon (1987) and Chandler and others (1993). On the basis of four-metric index of fish community condition, there is no evidence that the fish communities at sites in the Cascades and Eastern Cascades ecoregions were impaired (fig. 31). The lack of external anomalies and dominance of salmonids and sculpins (nearly 90 percent or more of abundance) at sites in the Cascades and Eastern Cascades was indicative of high quality cold water streams (Simon and Lyons, 1995).

The multimetric approach to assessing fish condition as applied to sites located in the Columbia Basin site group indicated that the fish community in Granger Drain (GRANG) was in poor condition (severely impaired). The percentage composition of tolerant individuals and omnivore/herbivores combined was the highest of any tributary site sampled. In addition, individuals with external anomalies were noted at this site, possibly indicating sublethal environmental stresses or chemically contaminated substrates (Meador, Cuffney, and Gurtz, 1993). Granger Drain was characterized by relatively high turbidity and nutrient concentrations, sedimentation (substrate embeddedness), and pesticides in filtered water and suspended sediment.

In the Columbia Basin site group, Satus Creek below Dry Creek (SATUSBDC), Umtanum Creek (UMTAN), and Ahtanum Creek (AHTAN) revealed little evidence of impairment of the fish community based on qualitative ratings. Cherry Creek (CHERRY), Satus Creek at gage (SATUSG), Wide Hollow Creek (WIDE), and Moxee Drain (MOXEE) were rated as moderately impaired based on fish community structure. These sites were characterized by relatively large numbers of tolerant individuals and large numbers of omnivore/herbivores or nonnative individuals. Agricultural intensity was rated as high at Moxee Drain and Wide Hollow Creek, suggesting that differences in physical characteristics between these two sites may account for differences in community structure.

Of the large-river sites in the Columbia Basin (Yakima River at Cle Elum [YRCE] was in the Cascades ecoregion and the fish communities there were rated unimpaired), the fish community at Yakima River at Umtanum (YRUM) was rated moderately impaired, whereas Yakima River sites at Parker (YRPARK), Toppenish (YRTOP), and Kiona (YRKIONA) were rated as highly impaired. Fish with external anomalies were collected at these highly impaired sites. Although the use of multimetric approaches for assessing fish condition in large rivers needs further testing and development (Reash, 1995), the presence of external anomalies alone may suggest possible chemical degradation at these sites.

Site rankings based on fish community conditions were closely related to agricultural intensity (NPAI index) (fig. 31). Fish community condition ratings at 17 of 21 sites (fig. 31) agreed with the NPAI. Only one site, Moxee Drain, was rated by the fish community conditions as being in better condition than the NPAI index indicated. Large-river sites where external anomalies were encountered (Yakima River at Parker, Toppenish, and Kiona) were rated as more impaired than indicated by the NPAI index. This close relation between the NPAI index and the condition of fish communities suggests that fish were responding to the environmental factors that are directly affected by agricultural practices and that maintaining fish communities in high quality condition will depend upon how agriculture is managed.

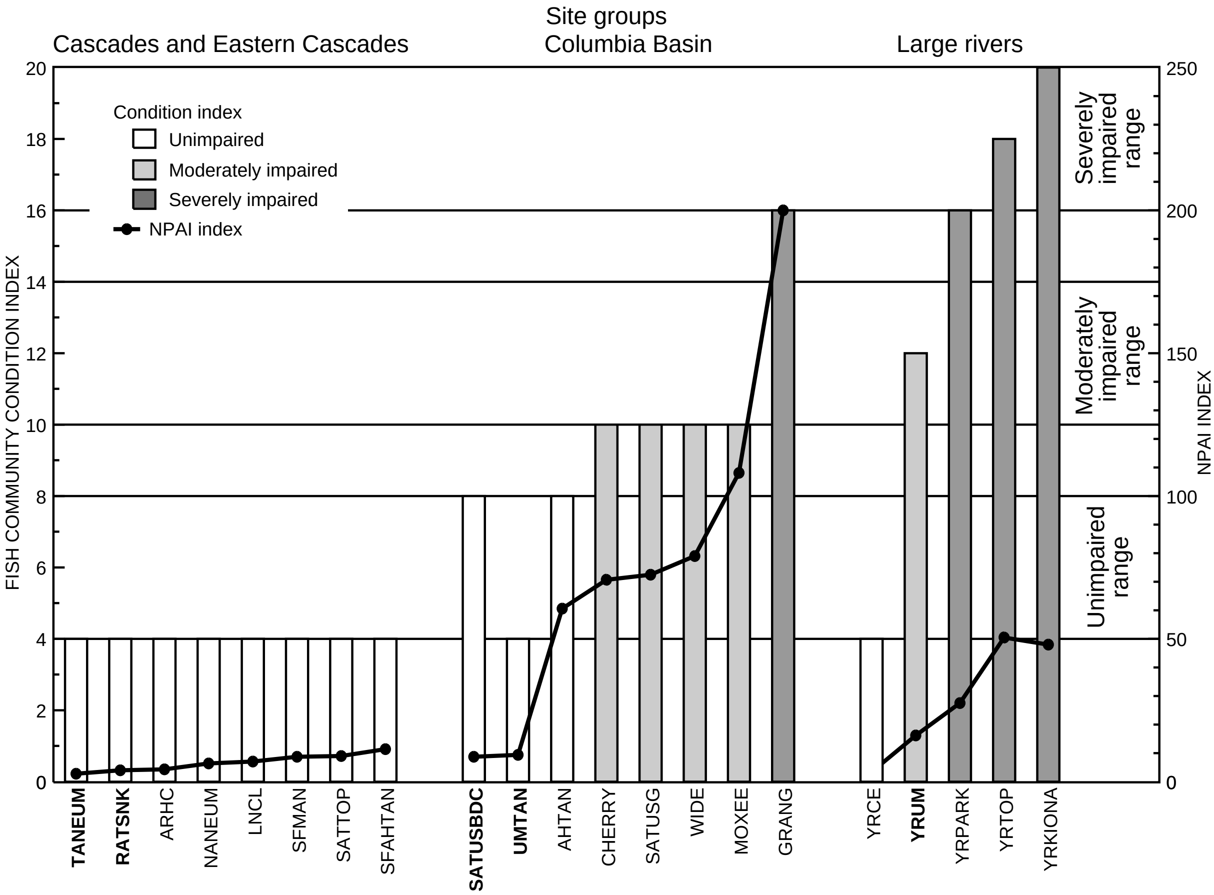


Figure 31. Relation between the multimetric fish-community condition index and the nonpesticide agricultural intensity (NPAI) index, Yakima River Basin, Washington, 1990. (Reference sites are shown in **bold** type. See table 30 for identification of ecological site abbreviations.)

Invertebrates

The condition of benthic invertebrate communities was determined using a multimetric condition index based on 20 community metrics. This index emphasizes the response of communities to disturbance throughout the Yakima River Basin and community differences between agriculturally impaired (Granger Drain, Moxee Drain, and Spring Creek [SPRING]) and unimpaired (Satus Creek below Dry Creek and Umtanum Creek) streams of the Columbia Basin site group. Community conditions were ranked relative to conditions at appropriate reference ("least affected") sites within the three site groups. The multimetric condition index (fig. 32) indicated that invertebrate communities at most sites in the Cascades and Eastern Cascades site group were unimpaired, with the exception of North Fork Teanaway River (NFTEA), Naneum Creek (NANEUM), and Little Naches River near Cliffdell (LNCL). Metals enrichment was apparent in the Cascades and Eastern Cascades site group, but the value of the multimetric condition index does not correspond to the value of either the metals index or the index of agricultural intensity (NPAI index), which is low for all sites. Community conditions in the Cascades and Eastern Cascades site group were probably related to the intensity of logging, which was not quantified in this study. From a statistical view, there is little difference in condition among sites in the Cascades and Eastern Cascades site group.

Three sites in the Columbia Basin site group (Moxee Drain, Spring Creek, and Granger Drain) had very low community condition scores (less than 25 percent of reference conditions), indicating substantial impairment and warranting a high level of concern for the invertebrate communities (fig. 32). Sites with high levels of impairment were associ-

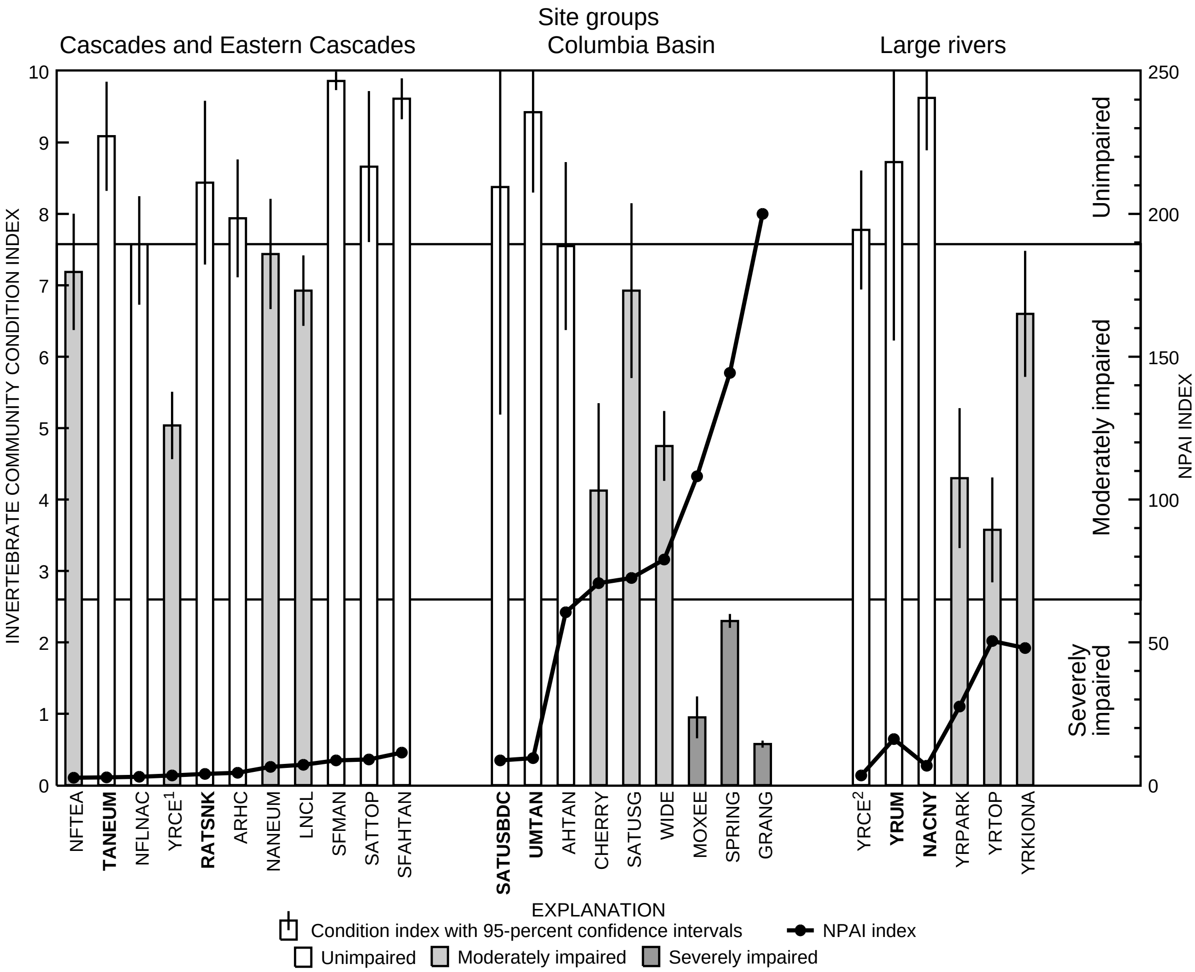


Figure 32. Relation between the multimetric invertebrate-community condition index and the nonpesticide agricultural intensity (NPAI) index, Yakima River Basin, Washington, 1990. (Reference sites are shown in **bold** type. See table 30 for identification of ecological site abbreviations. YRCE[1] represents the values if YRCE is included in the Cascades and Eastern Cascades site group, whereas YRCE[2] represents the values if YRCE is included in the large river site group.)

ated with high levels of pesticides and agricultural impairment (NPAI index) which, together with habitat impairment, were probably responsible for the poor conditions at these sites. Two other sites that received agricultural drainage (Cherry Creek and Satus Creek at gage) and one agricultural plus urban drainage site (Wide Hollow Creek) had multimetric condition indices that indicated a moderate level of impairment. Conditions at these sites were similar based on agricultural intensity (NPAI index), mean community condition scores (multimetric condition index), and the broad overlap of confidence intervals for the multimetric condition index (fig. 32).

Ahtanum Creek and the two Columbia Basin reference sites (Satus Creek below Dry Creek and Umtanum Creek) were ranked as unimpaired, indicating that the condition of invertebrate communities at these sites was very good. Total and EPT richness were similar at these sites and were the highest values observed in the Columbia Basin site group. Invertebrate communities at Satus Creek below Dry Creek and Umtanum Creek were expected to be unimpaired because these sites had low values for agricultural intensity, metals, pesticides, and disturbance. The intensity of agriculture at Ahtanum Creek was, however, at least six times greater than that of Satus Creek below Dry Creek or Umtanum Creek and was slightly less than sites that were rated as moderate concern (Cherry Creek, Satus Creek at gage, and Wide Hollow Creek). Values of the disturbance and pesticide indices (except pesticides in fish tissue) at Ahtanum Creek were, with the exception of the two reference sites, the lowest in the Columbia Basin site group, which may explain why this site was unimpaired. It is likely, however, that any increase in metals, agricultural intensity, or pesticides could decrease the multimetric condition index value and cause Ahtanum Creek to be rated as moderately impaired. Therefore, Ahtanum Creek is a site where community conditions could rapidly degrade if agricultural intensity or pesticide contamination were to increase even by relatively modest amounts.

Three sites in the large-river site group (Yakima River at Cle Elum, Yakima River at Umtanum, and Naches River at North Yakima [NACNY]) were rated as unimpaired by the invertebrate multimetric community condition index (fig. 32). All other sites in this site group were rated as moderately impaired. The value of the condition index dropped markedly along the main stem between Yakima River at Umtanum and Yakima River at Parker. This drop was accompanied by large increases in the value of the pesticide indices and a modest increase in agricultural intensity. Factors influencing community conditions here included (1) hydrologic modifications caused by irrigation and power diversions (Roza Canal, Selah-Moxee Canal, Moxee Canal, and Wapato Canal), (2) municipal wastewater discharges (Selah, Yakima, and Moxee City), and (3) irrigation return flows (Wide Hollow Creek, Moxee Drain, and Ahtanum Creek).

Yakima River at Cle Elum is a transitional site that has characteristics of both smaller streams of the Cascades ecoregion and larger streams of the Columbia Basin. If the multimetric condition index is recalculated by using the reference sites for the Cascades and Eastern Cascades site group, then the condition index at Yakima River at Cle Elum decreases from 7.8 ($YRCE^2$ in fig. 32) to 5.0 ($YRCE^1$ in fig. 32), which changes the condition rating from unimpaired to moderately impaired. Yakima River at Cle Elum can be considered to be both a moderately impaired site in the Cascades ecoregion group and an unimpaired site in the large-river site group.

Algae

The conditions of benthic algal communities in the Yakima River Basin were determined by categorizing taxa as tolerant, intolerant, or cosmopolitan depending on the correlation between relative abundance and nutrient concentrations and agricultural intensity. The reference sites used for the algal community condition index were the same ones used for determining the invertebrates community condition index. The numerical value of the algal community condition index primarily depends on the proportion of the community in each tolerance class (intolerant, cosmopolitan, and tolerant) and the reference sites against which the community is compared. The proportion of intolerant algae often exceeded 50 percent in the Cascades and Eastern Cascades site group, but rarely exceeded 10 percent in the Columbia Basin and large-river site groups. Data from the reference sites indicated that even relatively undisturbed sites in the Columbia Basin and large-river site groups did not support many intolerant algae. The natural differences in community composition that occurred among site groups made it very important that site conditions be determined by comparisons to reference sites specific to each site group.

The Columbia Basin site group, which contained sites with the highest levels of agricultural effects (NPAI and pesticide indices), also showed the highest levels of impairment (fig. 33). Four sites (Cherry Creek, Wide Hollow Creek, Moxee Drain, and Spring Creek) were rated as severely impaired, three sites (Ahtanum Creek, Satus Creek at gage, and Granger Drain) were rated as moderately impaired, and only the two reference sites were rated as unimpaired. Impairment was evident when the NPAI index exceeded 50, but the level of impairment did not appear to be linearly related to the level of the NPAI index.

The majority of the large-river sites were rated as unimpaired relative to the two reference sites, but the two sites farthest downstream (Yakima River at Toppenish and Yakima River at Kiona) were rated as severely impaired. Large-river sites were characterized by very low abundances of intolerant taxa. As with the Columbia Basin site group, impairment was evident when the NPAI index reached

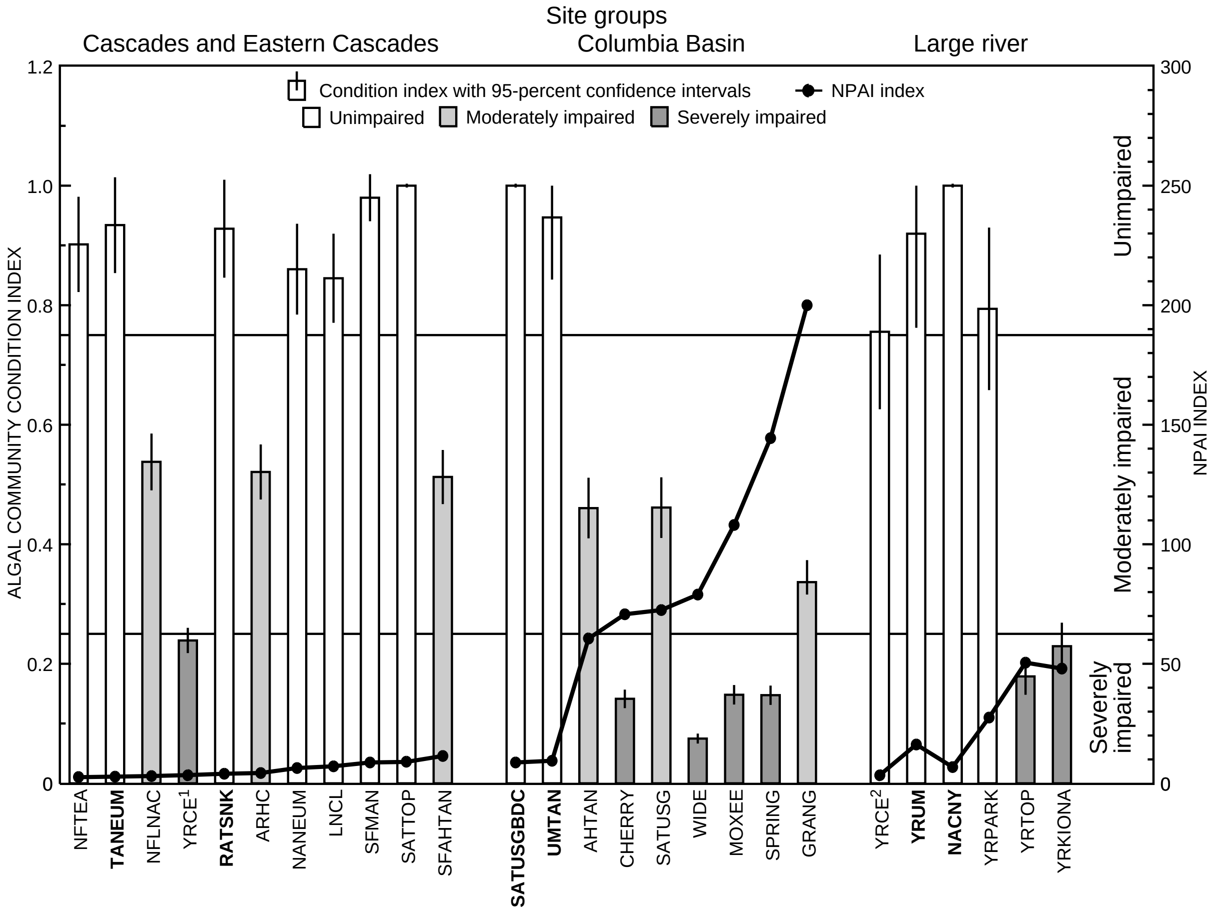


Figure 33. Relation between the multimetric algal-community condition index and the nonpesticide agricultural intensity (NPAI) index, Yakima River Basin, Washington, 1990. (Reference sites are shown in **bold** type. See table 30 for identification of ecological site abbreviations. YRCE[1] represents the values if YRCE is included in the Cascades and Eastern Cascades site group, whereas YRCE[2] represents the values if YRCE is included in the large river site group.)

about 50. The level of impairment was higher, however, at lower levels of the index than was evident in the Columbia Basin site group.

Three sites in the Cascades and Eastern Cascades site group were rated as moderately impaired and seven were rated as unimpaired. The degree of impairment in this site group did not appear to be related to agricultural intensity (NPAI index), which was low throughout the Cascades and Eastern Cascades site group (fig. 33). The moderate level of impairment at North Fork Little Naches River (NFLNAC), American River at Hells Crossing (ARHC), and South Fork Ahtanum Creek (SFAHTAN) probably corresponded to land disturbance associated with silvicultural practices, road construction activities, or grazing (Stuart McKenzie, U.S. Geological Survey, written commun., 1995). Algal communities at these three sites differed from other streams in the region by having a larger proportion of cosmopolitan or tolerant algae and a smaller proportion of intolerant algae. The severe impairment at Yakima River at Cle Elum may have been related to channel instability that occurred as a result of the construction of Interstate Highway 90. This site, however, was rated as severely impaired (YRCE[1] in fig. 33) only if it was compared to the small streams of the Cascades and Eastern Cascades ecoregions. It was rated as unimpaired (YRCE[2] in fig. 33) when compared to other large-river sites. Because Yakima River at Cle Elum is so much larger (drainage area 496 square miles and channel width 134 ft) than other sites in the Cascades and Eastern Cascades ecoregions (drainage areas less than 150 square miles and channel widths less than 50 ft), it is probably best to compare this site to other large-river sites and rate it as unimpaired.

The conditions of algal communities were very good in most streams in the Cascades and Eastern Cascades ecoregions, as indicated by low agricultural intensity (NPAI values generally less than 10), low nutrient concentrations, and a dominance of intolerant algal taxa. Communities were impaired in most streams and agricultural drains in the Columbia Basin ecoregion, as well as in the Yakima River downstream from the influence of these agricultural streams, as indicated by moderate to high agricultural intensity (NPAI values greater than 50), relatively large nutrient concentrations, and an abundance of tolerant taxa. The water quality of large-river sites in the Kittitas and Mid Valleys (Yakima River at Cle Elum, Yakima River at Umtanum, and Naches River at North Yakima), as well as in certain tributary streams (for example, Umtanum Creek and Satus Creek below Dry Creek), was relatively good. The lower Yakima River (Yakima River at Toppenish and Kiona) showed severe impairment.

Integrated Assessment of Site Conditions in the Yakima River Basin

Indices are useful tools for summarizing physical, chemical, and biological data and for relating these data to sites that are known to have good water quality (reference sites). Biological conditions ranged from unimpaired to severely impaired within the basin and the level of impairment varied with the type of community considered (figs. 31-33). The source of human engendered impairment was primarily agricultural practices (NPAI and pesticide indices), which affected sites in the Columbia Basin ecoregion.

Biological indices proved to be more sensitive indicators of site conditions than did physical and chemical measures, because the biological indices integrated effects arising from a broad range of factors, both measured and unmeasured (fig. 34). This was particularly evident in the Cascades and Eastern Cascades site group where water-quality conditions were generally good (the Cascades and Eastern Cascades site group had the fewest impaired sites). Invertebrate and algal communities identified some sites as having moderate levels of impairment when physical and chemical condition indices indicated no impairment. The metals index was the only physical and chemical index that indicated any impact in the Cascades and Eastern Cascades site group, but impairment associated with metals did not relate to biological impairment. These communities may have been responding to the effects of logging; however, intensity of logging was not directly quantified by the physical and chemical variables measured in this study, so community impairment could not be directly tied to logging. In contrast, the fish communities were not adversely affected. This suggests that fish communities are not as sensitive an indicator of effects in the Cascades and Eastern Cascades site group as are the invertebrates and algae. This may indicate that nonagricultural impacts differentially affect fish, invertebrates, and algae, or that differences in the life spans of fish (years), invertebrates (months), and algae (weeks) may influence how each community responds. Regardless of the cause, the invertebrate and algal community condition indices suggest that conditions at some sites may have declined relative to those at other sites in the Cascades and Eastern Cascades site group.

Sites in the Columbia Basin site group were all moderately or severely impaired with the exception of the two reference sites (Umtanum Creek and Satus Creek below Dry Creek), which showed no physical, chemical, or biological impairment. Three sites were heavily affected by agricultural practices (Granger Drain, Moxee Drain, and Spring Creek) and were listed as severely impaired by most of the physical, chemical, and biological condition indices. Ahtanum Creek, Cherry Creek, Satus Creek at gage, and Wide Hollow Creek had similar levels (moderate) of physical and chemical impairment, but Ahtanum Creek had less biological impairment than did the other three sites. Despite the similarity in impairment levels, Cherry Creek, Satus Creek at gage, and Wide Hollow Creek all had levels of pesticides that were much higher than at Ahtanum Creek, although the levels of agricultural intensity (NPAI index) were similar. Therefore, it is probable that community conditions in Ahtanum Creek could rapidly degrade if agricultural intensity or pesticide contamination were to increase even by relatively modest amounts.

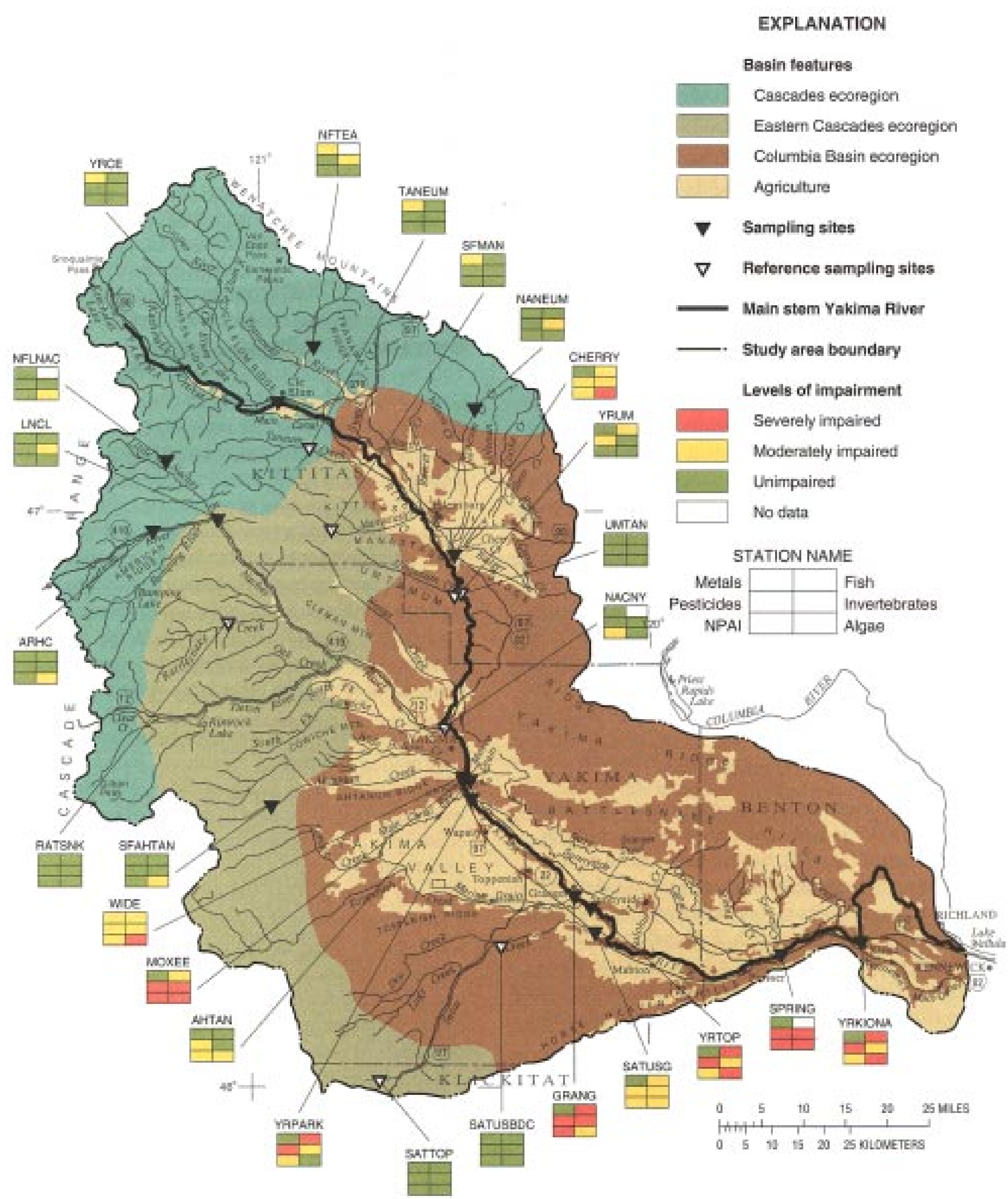


Figure 34. Ecoregions, environmental characteristics, and water-quality indices, Yakima River Basin, Washington, 1990. (NPAI, nonpesticide agricultural intensity. See table 30 for identification of ecological site abbreviations.)

Agriculture was the primary factor causing the impairment of biological communities in the Columbia Basin site group. The primary physical and chemical indicators of agricultural effects were nutrients, pesticides, dissolved solids, and substrate embeddedness, which all tended to increase with agricultural intensity. The biological effects of agricultural practices were manifested by a decrease in the number of species (taxon richness) and abundance of fish and invertebrates, a shift in algal communities to species indicative of eutrophic conditions, and higher abundances. Nutrients affect biological communities by stimulating the growth of eutrophic algae, which can cause shifts in the types of food available to invertebrate communities and the fish that feed on them. Pesticides, particularly insecticides, have toxicological effects that can directly reduce taxa richness and total abundance of the invertebrate community and, therefore, change both the algal (diminished grazing pressure) and fish communities (reduction in food). Increased substrate embeddedness restricts the interrock habitats used by many benthic invertebrates, thus forcing them into less desirable habitats and making them more vulnerable to predation. Collectively, these effects constitute major shifts in the food base for invertebrates and fish, which results in lowered production of sport fishes and increased production of less economically valuable species of fish.

Large-river sites located downstream from the city of Yakima had moderate to severe levels of impairment (fig. 34). Severe impairment of fish communities at these sites was associated with high levels of pesticides in fish tissues and the presence of external anomalies on fish. External anomalies were found at only one other site in the Yakima River Basin, Granger Drain, where the level of pesticides in fish tissue was high and there was substantial impairment of the fish community.

Pesticides that entered the main stem from tributaries where agricultural effects were very large (Moxee Drain, Granger Drain, and Spring Creek) were rapidly diluted, which would suggest that large-river sites should have fewer problems related to pesticides. The fish community condition index and the index of pesticides in fish tissues suggest, however, that pesticides are readily accumulated in these systems and that even low levels of pesticides in filtered water and suspended sediment are associated with a substantial impairment of the fish community and cause a risk to humans consuming these fish (Rinella and others, 1993). Lower trophic levels, invertebrates and algae, are not as sensitive an indicator of pesticide problems in large rivers as fish. Monitoring the status of fish communities in the main stem Yakima River provides managers with an effective tool for the protection of ecosystem and human health.

The condition of invertebrate and algal communities also indicated moderate to severe impairment at large-river sites downstream from the city of Yakima. Factors influencing fish, invertebrate, and algal communities at large-river sites included irrigation and hydropower diversions, municipal wastewater discharges, and irrigation return flows. Yakima River at Cle Elum is a large-river site located in the Cascades ecoregion. It is the only large-river site that showed no biological impairment when compared to other large-river sites, but it showed moderate to severe impairment when compared to smaller streams in the Cascades ecoregion. Therefore, Yakima River at Cle Elum was impaired relative to other sites in the Cascades ecoregion and unimpaired relative to other large-river sites.

Metals enrichment was not a significant factor in determining community conditions, but indices of agricultural intensity and pesticide contamination were significantly related to indices of community condition. This supports the conclusion that metals enrichment was only a locally important factor, particularly in the Kittitas Valley, but agricultural effects (pesticides and nutrients) were the dominant water-quality issue throughout the basin. Pesticide and nutrient effects were strongly correlated with one another and with some physical measurements (water temperature), which suggests a link between the effects of pesticides, fertilizers, and habitat in the Yakima River Basin that is important to consider when devising management strategies for monitoring and manipulating water quality. For example, the strong correlation between the NPAI index and indicators of invertebrate and algal community condition suggests that nutrient surveys could be a cost effective means of monitoring agricultural effects on invertebrates and algae. Effects on fish communities, however, might be better monitored by measuring pesticides in fish tissues, because the fish community condition index is more closely related to pesticides in fish tissues than to the NPAI index.

Basinwide correlations between biotic and physical and chemical indicators of site conditions only partially described the relation between environmental and biological conditions. Direct examination of the response of fish, invertebrates, and algae to agricultural intensity (NPAI index) suggests some unanticipated responses that have important implications for the management of biological water quality in the Columbia Basin. Fish showed an almost linear decline in community condition (conditions decline as the value of the fish community condition index increases) as the level of agricultural intensity (NPAI index) increased (fig. 35). This implies that any increase or decrease in agricultural intensity will be accompanied by a corresponding increase or decrease in the index value representing the condition of the fish community, and the response of the fish community could be determined anywhere along the gradient that represents agricultural intensity (NPAI index). The data for benthic invertebrates and algae, though limited, suggest that these two communities do not display a linear response to agricultural intensity (fig. 35). Instead, the condition of invertebrate and algal communities appears to deteriorate very rapidly once a relatively low threshold (NPAI index between 20 and 60) of agricultural intensity is reached (conditions decline as the invertebrate and algal community condition index decreases). This rapid decline develops a community that shows little response to increases in agricultural intensity. This pattern of response suggests that mitigation efforts conducted at sites with high agricultural intensity probably will not produce meaningful improvement. In contrast, relatively modest mitigation efforts at sites where the level of agricultural intensity is near to the impairment threshold will probably produce large improvements in community conditions at relatively modest costs.

These data also suggest that, if the objective of an integrated monitoring program is to understand the relation between water quality and land use, then it is critically important to determine the responses of invertebrate and algal communities at low levels of agricultural intensity, because community responses can be very rapid and can occur at relatively low land use intensities. Monitoring programs that focus on finding high concentrations of agricultural chemicals (that is, occurrence studies) probably will not adequately represent the response of biota to agriculture. This can lead to erroneous conclusions regarding the effects of agriculture on human and environmental health. The manner in which the biota respond to changes in land use is critically important to the development and implementation of cost effective mitigation procedures. If the communities show a threshold response, then the apparent success (that is, effectiveness and cost) of a mitigation procedure will greatly depend upon where the site lies along the land use distribution relative to the impairment threshold. If the site lies close to the impairment threshold, then mitigation is likely to show large effects and to be judged as successful. If it lies farther away, then the same mitigation techniques will probably produce little improvement and will be judged as unsuccessful. Therefore, it is critically important to determine whether the community responds to the type of land use and, if it does, the form of that response must be known before cost effective restoration can be achieved.

The response of the invertebrate and algal communities of the Columbia Basin site group to agriculture has far reaching implications for managing water quality in the Yakima River Basin. Therefore, the next implementation of biological programs in the Yakima River Basin should be designed to better define the existence and form of these responses. Such a design would include sampling more sites, obtaining a better, more comprehensive representation of the agricultural gradient, and including sites with similar levels of agricultural intensity (redundant sampling).

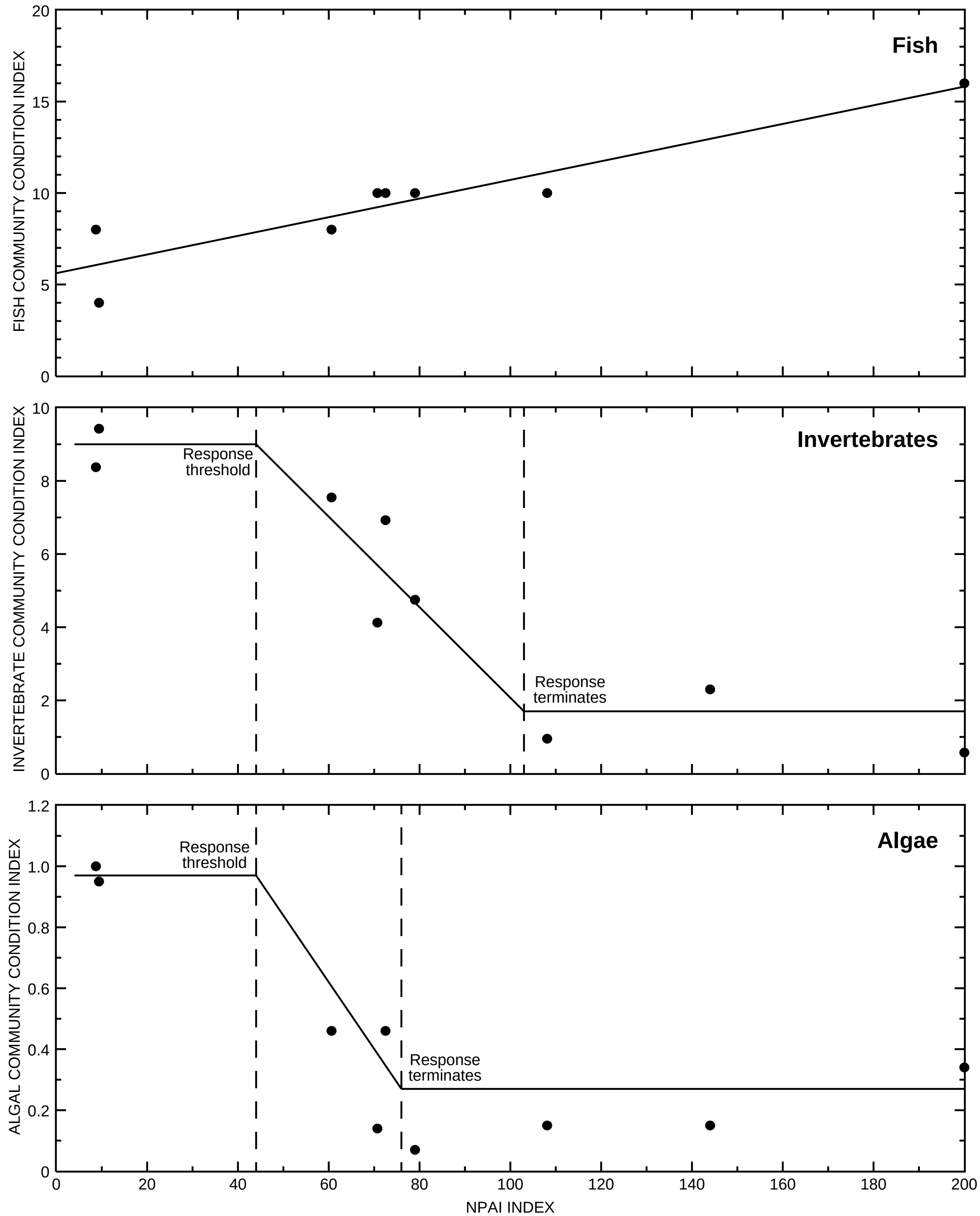


Figure 35. Response of fish, invertebrate, and algal community condition indices to agricultural intensity (nonpesticide agricultural intensity [NPAI] index) in the Columbia Basin site group, Yakima River Basin, Washington, 1990. (The fish-community condition index increases as conditions deteriorate. The invertebrate- and algal-community condition indices decrease as conditions deteriorate.)

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